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The Physical Limnology of Great Slave Lake

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INTRODUCTION

Great Slave lake occupies a place of special interest among the large lakes of the world. It lies in a region for which limnological studies are as yet almost lacking; its cold climate and great size and depth place it close to the ultimate in oligotrophic condition; and it had in 1944, the further attraction of an unexploited fish population. It was therefore with great interest that we undertook, in 1944, a four-year programme of limnological and fisheries investigations under the auspices of the Fisheries Research Board of Canada. Reports already published have dealt with the general survey and its application in estimating the fish production of the lake (Rawson 1947 and 1948) and with the ecology of two important crustaceans in the lake (Larkin 1948). The present contribution is concerned with the physical and chemical features of the aquatic environment in Great Slave lake.

THE GEOGRAPHICAL SITUATION

Information concerning the geography of Great Slave lake has been accumulating over the past 175 years. As a link in the waterway to the Arctic and the source of the great Mackenzie river it has become one of the better known features of northwestern Canada. The accounts of the early explorers and fur traders contain information which is still of more than historical interest. Samuel Hearne (1775) reached the lake in the winter of 1771-1772 and Alexander Mackenzie (1801) went through it in 1789. Richardson's (1851) account of the Franklin search is one of the richer of the early sources. Preble (1908) gives a full account of the first expedition which was primarily biological in purpose, while Camsell and Malcolm (1921) provide the first extensive treatment of the geology of the area. The main study of the topography around Great Slave lake was carried on by Blanchet whose papers of 1925 and 1926 include also important observations of geology and natural history. Mineral discoveries during the past twenty-five years have stimulated much geological investigation. Biological studies have been much less numerous, but important work has been done by Raup (1928 to 1946), Clarke (1940), Soper (1941) and others. Recent interest in arctic research and in the planned use of northern resources has

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accelerated investigation of the Mackenzie region. Some conception of this development may be obtained from the publication *Canada's New Northwest*, issued by the North Pacific Planning Project, under the direction of Charles Camsell (1947). Many of the reports cited above contain extensive bibliographies and critical discussion of the earlier work.

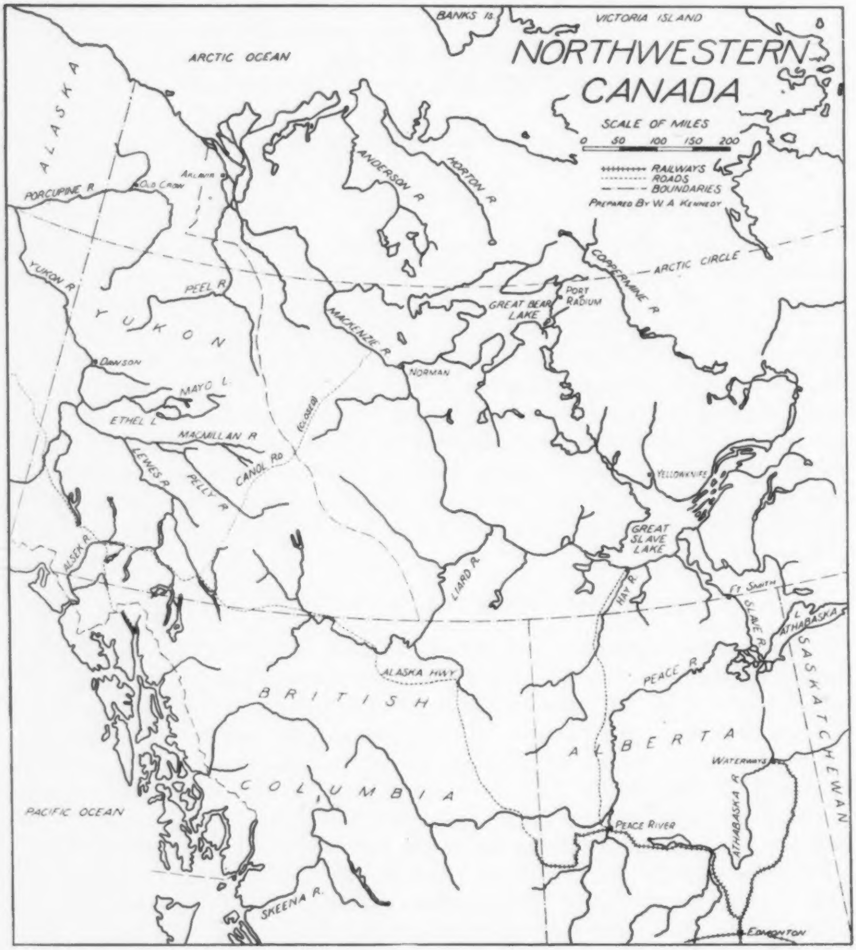

FIGURE 1. Northwestern Canada showing the location of Great Slave lake in the Mackenzie river drainage.

Great Slave lake (fig. 1) is found between latitudes 61° and 63° north and longitudes 109° to 117° east, lying thus in the southwest portion of the District of Mackenzie. The western expansion of the lake is in the Mackenzie lowlands but a long east arm cuts far into the Precambrian rocks of the Canadian Shield.

In the sections which follow the geological and physiographic surroundings will be considered as a background for more detailed studies of conditions within the lake.

Geology

Two contrasting physiographic provinces are represented in the area around Great Slave lake. The Mackenzie lowlands at the west is underlain by Palaeozoic rocks mostly of Devonian age. A narrow strip of Silurian and Ordovician forms the east margin of the lowlands, thus adjoining the Precambrian rocks of the Canadian Shield (fig. 2). The second physiographic province is a part of the Canadian Shield, formed in this area mostly of crystalline rocks but with some important exposures of metamorphosed sedimentary and volcanic rocks.

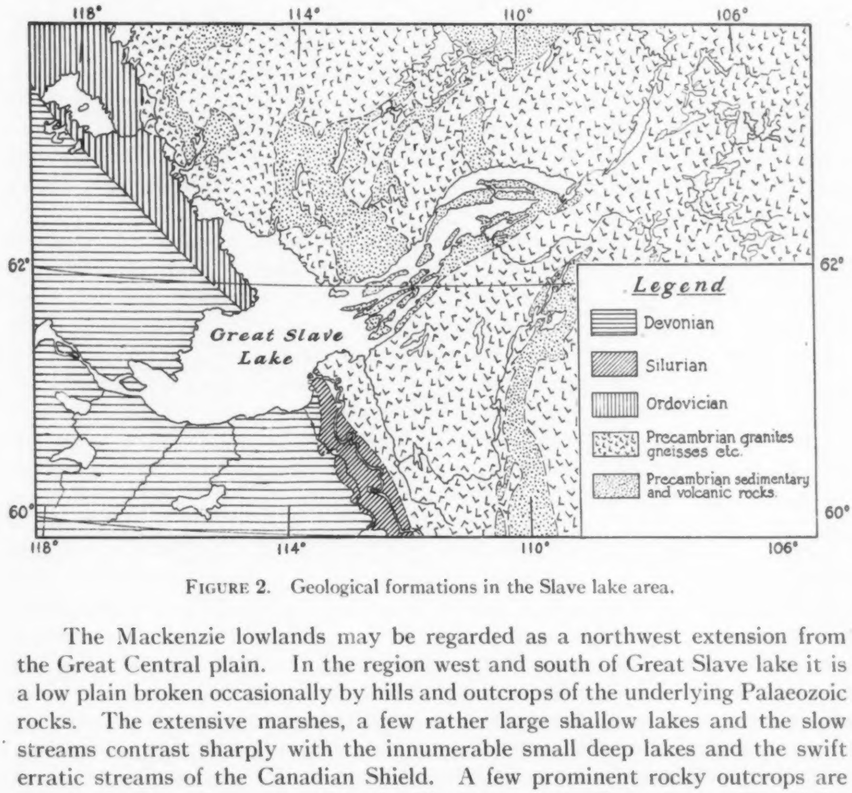

Figure 2. Geological formations in the Slave lake area.

The Mackenzie lowlands may be regarded as a northwest extension from the Great Central plain. In the region west and south of Great Slave lake it is a low plain broken occasionally by hills and outcrops of the underlying Palaeozoic rocks. The extensive marshes, a few rather large shallow lakes and the slow streams contrast sharply with the innumerable small deep lakes and the swift erratic streams of the Canadian Shield. A few prominent rocky outcrops are seen in the Devonian part and in the Silurian near the Slave river. Grey dolomitic limestones are seen along the Slave river and at Gypsum and Redrock points on the northwest shore of the lake. The extensive soils of this area had their origin chiefly from glacial drift, with small areas of alluvial and lacustrine deposits at the lower altitudes.

The Precambrian formations on the high lands adjacent to the eastern half of the lake (fig. 2) exhibit the rugged topography characteristic of the Canadian

Shield. Rough hills, mostly of granite and gneiss, rise 200 feet or more and scattered among them are lakes of all shapes and sizes. At Gros Cap, where the east arm joins the main lake, the hills are 100 to 200 feet high. They increase in height toward the east end where some hills and escarpments rise to about 1000 feet above lake level. The area is predominantly one of Archaean granites and granitoid gneisses but, as may be seen in fig. 2, extensive precambrian sedimentary rocks are found from Yellowknife eastward and around Christie bay in the east arm. The oldest of these rocks belong to the Point lake-Wilson island group (Stockwell 1932). They are highly metamorphosed and greatly altered by later intrusives. Above them lie the Slave lake and Et-then series of less altered sedimentary rocks. There is little soil on these precambrian rocks except for small depressions with boulder clay or glacial drift. The dominant granitic rocks weather slowly but the later precambrian sedimentary rocks have in a few places formed a thin residual soil disturbed but not entirely removed by glaciation. Raup (1946) has observed the effects of this differential weathering on the vegetative cover. The low mineral content of the water in McLeod bay as compared to that of the remainder of the lake, is believed to be a result of its receiving water only from the Precambrian while the main lake drainage comes from a variety of rock and soil formations.

The glaciation of this area is largely responsible for the present form of the Great Slave lake basin. The direction of ice movement as deduced from striae (Stockwell 1933 and others) and more recently from drumlinoid forms observed in air photographs (Wilson 1939) has been indicated on geological maps for areas all around the lake. The majority of these strike between southwest (225°) and west (270°). Local variations can often be related to diversion of the ice into valleys. Thus north of McLeod bay striae indicate a southward movement into the depression (Wilson 1939). The Pleistocene ice sheet apparently moved southwest through the valley, gouging and plucking out the rocks to form the deep basins now occupied by McLeod (900 feet) and Christie (2000 feet) bays. Between these a huge diabase sill, forming much of the Pethei peninsula, resisted erosion. Farther west, the Hearne channel was cut down to 1000 feet. Faults paralleling the direction of the arm have given rise to various escarpments. The most outstanding of these runs from the Slave river along the south shore of the east arm, passing 10 miles south of Snowdrift, fig. 7, and straight across country to the Dickson canyon on the Thelon river (Wilson 1939). The width and the cross-sectional contours of McLeod and Christie bays suggest that glacial deepening rather than faulting was chiefly responsible for the formation of the deep bays. We may note that Alcock (1920) postulates a similar origin for lake Athabaska.

At the western margin of the precambrian the ice sheet apparently spread out from the confines of the "east arm." It plucked away the softer Palaeozoic rocks along the Yellowknife shore and pushed westward spreading its materials across the Mackenzie lowlands and producing a basin which becomes gradually shallower toward the western shores. Overrunning the western margin of the lake the lobes of the ice sheet pushed far up the present valley of the Hay river and down the Mackenzie valley.

The precursor of lakes Athabaska and Slave was formed by the retreat of the ice sheet, a process interpreted by Cameron (1922) as indicated in his maps reproduced here as fig. 3. The first map, indicating a level of 1600 feet, shows an ice lobe extending about 100 miles, and the impounded water an additional 90 miles, up the Hay river valley. A second lobe of similar size blocked the Mackenzie valley, so drainage must have been southeast to Hudson bay.

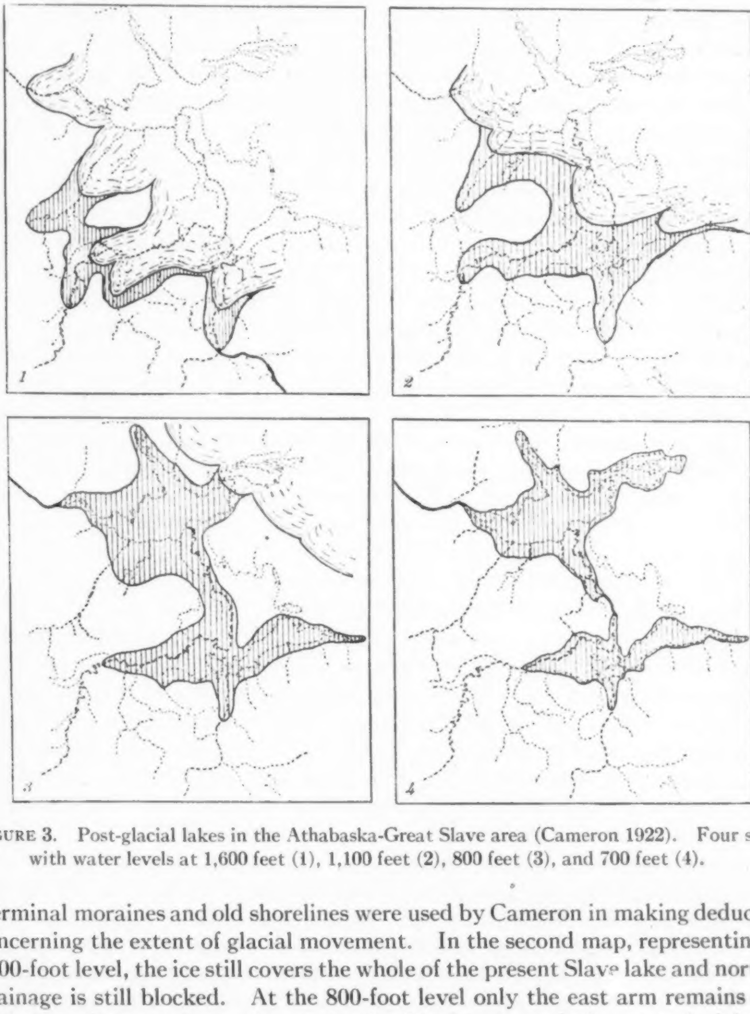

FIGURE 3. Post-glacial lakes in the Athabaska-Great Slave area (Cameron 1922). Four stages, with water levels at 1,600 feet (1), 1,100 feet (2), 800 feet (3), and 700 feet (4).

Terminal moraines and old shorelines were used by Cameron in making deductions concerning the extent of glacial movement. In the second map, representing the 1100-foot level, the ice still covers the whole of the present Slave lake and northern drainage is still blocked. At the 800-foot level only the east arm remains filled with ice, drainage is northwest to the Mackenzie and the post-glacial lakes "Great Slave" and "Athabaska" are broadly connected through the region of

the present Slave river. At 700 feet the general form of the present lake is established but a considerably larger area is covered and a long south arm extends up the Slave valley giving the lake a cross-shaped outline. Old shorelines from about this stage can be observed at many places around the lake. Windy point, on the west shore shows a fine series of beaches extending over an elevation of some 250 feet (Cameron 1922). In the east arm elevated shorelines have been recorded at about 540 feet above the present lake level (Stockwell 1933). Differential elevation is believed to account for these. Differential adjustments are also deduced by Cameron in the western part of the basin. As the water level declined toward its present position the great quantities of sediment brought down by the Athabaska and Peace rivers filled in the old south arm of the lake with alluvial deposits. The Slave river still cuts its way through these sediments and its delta is pushing out into the lake.

The glacial history is sufficiently known to say that Great Slave is a very young lake. The recessional stages of the last ice sheet in this area are believed to be approximately equivalent to those of the late Wisconsin as known in Manitoba and Ontario. Thus the post-glacial lakes "Slave and Athabaska" would be contemporary with lake Agassiz. Antevs (1931) estimates that glacial ice was still present between 7,500 and 9,000 years ago. It is possible therefore that Great Slave lake may not be more than 10,000 years old. In this connection we may note McConnell's (1891) observation that the Alexandra falls (see p. 16 below) on the Hay river has cut back through the limestone escarpment a distance of about six miles. It is of interest that Niagara falls have receded by about the same amount but the amount of flow has varied greatly and the time periods may have been quite different.

Vegetation

The vegetation in the Athabaska-Great Slave area has been studied by H. M. Raup over a period of twenty years. In a recent paper (1946) he deals broadly with the phytogeography of the region, considering the relations of the flora to geology, soils and climate. He has classified the vegetation and has made interesting deductions as to the age of the forest types. His conclusions are of particular interest to the limnologist since the processes of soil formation which limit the development of vegetation are also important in the accumulation of nutritive materials in the lake water and thus in the development of the flora and fauna of the lake.

The forests around Great Slave lake are recognized by Raup (1946) as of four types. The thin forest which characterizes much of the precambrian area he denotes as "Park-like white spruce." This is essentially equivalent to the Northern Transition section of Halliday's (1937) classification. It surrounds the east arm of the lake from Et-then island eastward and meets the tundra about 40 miles east of McLeod bay. The dominant white spruce is associated with white birch and numerous lichens. The forest on the remainder of the pre-

cambrian area is called by Raup, "Jack-pine forest." This comprises a narrow zone along the east shore of the north arm, the islands west of Et-then, and a wide area east of the Taltson river. Halliday includes most of this area in his Northern Transition section. The jack-pine is abundant on sandy plains and rocky hills. Predominant ground species in this section are the bear-berry and lichens.

The forest on the Mackenzie lowlands northwest of the lake is described by Raup as "upland mesophytic spruce." The same formation is found in the Caribou hills area south of Buffalo lake. It is characterized by a moderate growth of spruce interspaced with extensive muskegs in the poorly drained areas. Fire, and the resulting ingress of jack-pine and poplar have altered large areas of this section. Across the south shore of the lake and extending up the Slave river is the fourth type, the "flood-plain white spruce" forest. This area is co-extensive with the former "south arm" of Great Slave lake as indicated by Cameron, fig. 2, at the 700-foot level. The white spruce is in many places mingled with balsam, poplar and willows. The best growth of spruce is found in the deltas and on rich alluvial soils near the river-bank. In the area west of the Slave delta poorer forest growth and more muskegs are evident. This formation continues down both sides of the Mackenzie river and extends up the west shore to Sulphur bay.

Raup emphasizes the general correlation of vegetative cover with rock composition and glacial history in the area. The Palaeozoic formations of the Mackenzie lowlands lie nearly horizontal and are relatively soft. Thus they received a widespread layer of till and outwash and their component rocks were readily broken and weathered. The Precambrian area with its predominantly granitic rocks has resisted weathering and has produced very little soil. In the smaller areas of Precambrian sedimentaries the limestones, shales and dolomites have weathered faster and have produced a thin residual soil. These areas and others where glacial till has been deposited, have a richer flora which Raup describes as standing out like oases against the thin vegetative cover of the crystalline rocks.

Climate

The climate in the area under consideration may be described as northern continental. The winters are long and cold, the summers short and warm, and the annual precipitation is low. The moderating effect of the large water area is important at locations near the lake. Halliday (1937), in attempting to define the climatic features of the forest zones, has made use of Thornthwaite's indices to arrive at a quantitative description of the climate. The Mackenzie lowlands section is described as having a cool temperate and sub-humid climate, with a high (76%) summer concentration of heat and a moisture deficiency both summer and winter. Observations in the Northern Transition forest are scarce but data from a single station indicate a lower temperature efficiency index and a higher precipitation effectiveness than that of the lowlands.

Temperature and precipitation data for three stations on Slave lake are given in table I, along with comparative figures for four other stations ranging from Fort Chipewyan at the west end of lake Athabaska, to Port Radium on Great Bear lake.

TABLE I. Temperature and precipitation at Great Slave lake and in adjacent areas.

	Mean Temperature ° F.					Frost-free days	Mean Precipitation, inches			
	Annual	January	June	July	Aug.		Annual	Summer	Snow	Snow % of total
Fort Chipewyan (L. Athabaska)	26.9	−13.1	55.2	61.8	58.3	74	12.6	5.2	45.5	36
Fort Smith	24.6	−16.0	54.2	60.4	56.0	56	13.0	5.8	37.3	29
Fort Resolution	23.2	−16.7	52.3	60.3	54.3	93	11.6	3.7	51.9	45
Hay River	23.7	−15.6	50.0	59.4	56.8	87	11.8	4.4	45.6	39
Yellowknife (5 years)	22.8	−14.2	53.0	60.5	57.3	112	8.2	3.0	37.3	46
Fort Simpson	23.7	−18.3	56.1	61.7	57.2	84	13.0	5.0	54.6	42
Port Radium (6 years)	20.1	−12.6	48.8	52.6	50.4	73	6.5	2.4	28.2	43

The mean annual temperature at the lake is just above 23° F. The January temperatures of −14° to −16° indicate a cold winter. The length of winter is attested by the average duration of ice cover of more than 5 months. The summers however are very warm with means for June, July and August ranging from 50° to 60° F. This, coupled with summer days of from 15 to 19.5 hours of sunlight, produces a vigorous growing season. Summer temperatures at Great Slave lake are much warmer than its northern location would suggest. The mean for June, July and August is about 55° F. The isotherm for this temperature touches the western extremity of Great Bear lake, cuts through the middle of Great Slave, touches the east end of lake Athabaska, crosses Reindeer lake and follows a course not far east of lake Winnipeg to the Lake of the Woods. Thus most of the large lakes in northwest Canada lie in areas of similar summer temperatures.

The moderating effect of the large body of water is best illustrated by the average frost-free period of 84 to 112 days at Great Slave lake as contrasted to 56 at Fort Smith and 68 at Fort Vermilion. In the great wheat-growing lands centering about Grand Prairie in the Peace river valley of Alberta, the average frost-free period ranges from 74 to 78 days.

Precipitation is low all through the Slave lake area and decreases northward, from 13 inches at Fort Smith to 8.2 at Yellowknife and 6.5 at Port Radium. About one-third of this falls during the summer months of June, July and August. The average snowfall varies from 37 to 52 inches at stations in the area and the snow usually contributes more than 40 per cent of the total precipitation.

Wind data are available for Fort Smith over a ten-year period and from Resolution, Yellowknife and Port Radium for about three years. The wind roses in fig. 4 show the percentage frequency of winds from various directions in summer and winter. In general northwest and southeast winds predominate. In summer Resolution experiences many winds from west, northwest and north, all across a considerable body of the lake. Yellowknife gets most of its summer winds from northwest and north with very few off the lake. The area is not one of high winds. Mean monthly averages at Fort Smith range from 5.3 miles per hour in January to 7.8 in May. However, storms of magnitude capable of disrupting fishing operations are not uncommon during the fishing season which usually runs from about June 25 to September 15. In the summer of 1946 storms

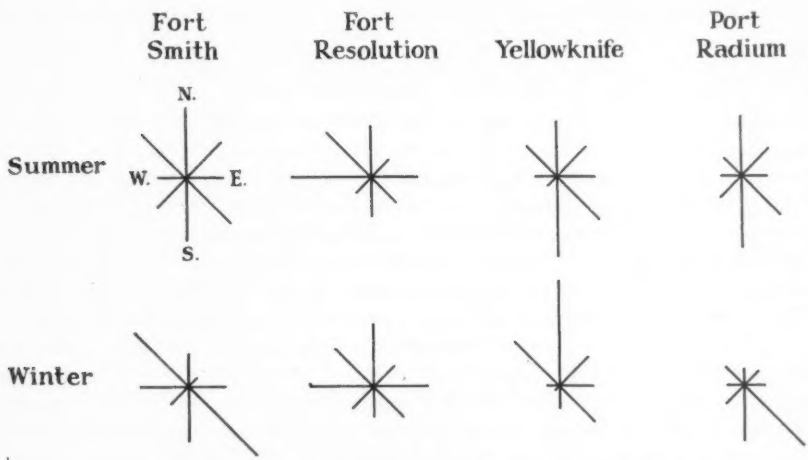

FIGURE 4. Wind roses showing the percentage frequency of winds from various directions at four stations in the Mackenzie valley.

were few and scattered but with some concentration in early September. In 1947 storms were infrequent during the early part of the season but common in September and severe during an extension of the fishing season, September 15 to 22. In 1948 storms were much more numerous than in the two preceding years with unfavourable periods in mid-July and again from August 18 to 26. Although conditions varied greatly in the three summers it might be said that an average of about eight storms per season were of sufficient intensity to prevent at least three-quarters of the fishermen from lifting their nets.

Permanently frozen subsoil is characteristic of much of the area around Great Slave lake. A continuous layer of permafrost has been reported from Providence, Yellowknife and Rivett lake, north of McLeod Bay. Areas of permafrost are known also at Hay River, Resolution, the banks of the Slave river and at Snowdrift; but in these southern localities it is believed to be in the form

of "islands" rather than in a continuous layer. The margin of continuous permafrost is somewhere near the mean annual isotherm for 23° F. which cuts across the lake from east to west. At Yellowknife the permafrost is reported to extend from a few feet below the surface to depths of 200 and 300 feet. It is most obvious in the muskegs which often thaw no more than 1.5 to 2 feet during the summer. Under forest cover thawing may be somewhat deeper but even under cultivated soils along the south boundary of the lake, permafrost has been found at depths of 3.5 to 8 feet. The effects of frozen subsoil on the development and distribution of vegetation has been discussed by Raup (1941), Porsild (1938), Jenness (1949) and others. The vegetation and soils of the area are important as sources of primary nutrients for the lake. The permafrost affects the vegetation, the drainage process and the rate of organic decomposition in the soil. In all of these ways it must influence the flow of nutrient materials to the lake.

Drainage

The Mackenzie river drains an area of 682,000 square miles, more than one-fifth the area of Canada, exclusive of the arctic islands. This is larger than the drainage of the St. Lawrence and second only, on this continent, to the Mississippi. The Mackenzie basin includes part of the Cordillera on the west. Its central portion is a part of the Great Central plain which continues northwest as the Mackenzie lowlands. On the east it drains a considerable area of the margin of the Canadian Shield. Thus the basin includes parts of British Columbia, Alberta, Saskatchewan, the Yukon and a large section of the Northwest Territories.

The Slave river drains 234,000 square miles, approximately the upper third of the Mackenzie basin. Local rivers drain an additional 150,000 square miles into Great Slave lake. The available records for flow in the Peace, Athabaska and Slave rivers have been used in estimating the average annual inflow from the Slave river at about 118,000 cubic feet per second. The seasonal flow varies from about 55,000 to 75,000 c.f.s. in the period from November to March and rises to a maximum of about 230,000 c.f.s. in June and July. Records of inflow from other rivers to Great Slave lake are scanty and in most instances they cover only a few years. The Yellowknife river has had a mean annual flow of 745 c.f.s. over a period of ten years. The mean annual inflow from the Lockhart river is probably of the order of 3,000 c.f.s. and from the Snare about 1,300. These and scattered measurements from other streams have been used in estimating the total inflow to Great Slave lake from local drainage at 25,000 c.f.s. In a previous paper (Rawson 1947) it was estimated that the Mackenzie river leaves Great Slave lake with an average discharge one and one-half times that of the Fraser and two-thirds that of the St. Lawrence at the outlet of lake Ontario.

The rivers entering Great Slave lake from all sides affect the physical conditions in the lake and they are of considerable importance in the life histories of certain species of fish. In the Mackenzie lowlands area to the southwest of the lake there are three rivers, the Hay, Buffalo and Little Buffalo. Arising on the precambrian area and flowing north to the east arm of the lake are the Taltson

and Snowdrift rivers. The Lockhart, Yellowknife, Snare and several smaller rivers drain the precambrian area north and east of the lake. There are no streams of any importance entering the lake on its west shore. The watershed from Rae to the source of the Mackenzie river is relatively narrow and most of the territory west of the lake drains through the Horn river to the Mackenzie. It is probable that the run-off per unit area from the rocky precambrian territory is more than double that from the poorly drained lowlands section.

The Hay river has a drainage area of 19,200 square miles, the largest among the local rivers although its discharge at the lake is probably less than that of the Lockhart or Taltson rivers. It rises in northeastern British Columbia and flows northeast for about 300 miles. The upper part of its course is through rolling drift-covered territory, then a long flat stretch of muskeg and brule. About 80 miles from the lake the edge of the Alberta plateau is marked by great outcrops of Devonian limestone. Rapids appear and then the Alexandra fall, a sheer drop of 105 feet. A second drop of 41 feet, the Louise fall, is found a mile below. A deep gorge, six miles in length leads to the edge of the escarpment. The lower 40 miles of the river are slow and it enters the lake through a small delta in which there is a much needed but rather difficult harbour.

The Buffalo river is about 30 miles east of Hay river. Its source is at Buffalo lake, a large but extremely shallow basin which receives the drainage from the northern slopes of the Caribou hills. The river is about 60 miles in length. Its upper half runs through relatively flat country swinging east to the Big Bend. From this point it cuts more deeply into morainic ridges and glacial drift. Rapids are frequent especially where outcroppings of limestone occur. The lower three miles of the river are slower but have some rapid stretches. The Little Buffalo river arises at Conibear lake on the Alberta plateau. It runs east near the Salt river and then north to parallel the lower part of the Slave river. It enters the lake in a very shallow bay about 12 miles south of Resolution. The volume of its inflow is quite small but of some interest since it carries a heavy concentration of salt into the lake.

The Taltson drains a large area, 17,500 square miles, southeast of Great Slave lake. Its tributaries rise at such great distances as Tazin lake, just north of lake Athabaska and from a point nearly 200 miles east where the watershed adjoins the Thelon. The river courses are very erratic and broken by many connecting lakes of which the largest is Nonacho. The main branch flows south, then west and finally north to the lake. The lower stretch of about 70 miles follows the margin of the outcrop of precambrian rocks and roughly parallels the Slave river. The Snowdrift river drains a smaller area of about 2,700 square miles. It rises at Eileen lake, near the Thelon and flows west, descending some 600 feet from the high land in a series of falls below Siltaza lake. This rapid descent in a short stretch of 15 miles is in contrast with the Taltson river where the major falls are distributed over some 120 miles.

The Lockhart river has a drainage area of about 10,000 square miles. It rises at MacKay lake, runs east through Aylmer and Clinton-Colden and circles south through Artillery lake to enter the east end of McLeod bay. The last

section of 20 miles drops about 670 feet through rapids and falls, of which the Parry Falls of 130 feet is the most spectacular.

Along the north shore of McLeod bay there are several small rivers of which the Hoarfrost is the most prominent. It rises at Walmsley lake and flows southwest to enter the bay at a sixty-foot drop over a series of falls. Most of the streams from Taltheilei narrows west are small. The Beaulieu river which flows into the lake 15 miles east of Gros Cap drains the interior of this area. It rises south of MacKay lake and runs about 120 miles to the southwest, draining about 2,500 square miles. In the lower 50 miles there are several falls but the volume of flow is relatively small.

The Yellowknife and Snare rivers which enter the north arm of the lake are well known because of mining and consequent power development in these areas. The discharge of the Yellowknife river into Prosperous lake averaged 745 c.f.s. in the ten years following 1937. This is the run-off from about two-thirds of the drainage area of the Yellowknife river. The total drainage is about 6,300 square miles. A power plant at the outlet of Bluefish lake makes use of a head of 110 feet to supply the mines and townsite at Yellowknife. The Snare river drains another 6,200 square miles which lie just north of the Yellowknife drainage. It passes through Slemon and Russell lakes to enter Marian lake near Rae. The discharge of the Snare river from 1945 to 1947 averaged 1,330 c.f.s. from a drainage of 6,000 square miles. The district west of the Snare river is drained by the Emile river which enters the north end of Marian lake.

MORPHOMETRY

Dimensions and Shoreline

Great Slave lake measures 440 km. (275 miles) from Reliance to the source of the Mackenzie river and 160 km. (100 miles) from the Slave delta to Fort Rae (fig. 5). The large body of open water is about 50 by 100 miles and has its long axis in line with the east arm. The latter is 150 miles in length and much broken up by islands and peninsulas, figs. 6 and 7. The "north" arm extends about 90 miles northwest toward Rae. In the early history of the lake another arm extended up what is now the Slave river valley, to give the lake a symmetrical cross-shaped outline, fig. 3. This "south arm" is now filled in and the Slave river delta has pushed at least 10 miles north from the general line of the south shore.

The shoreline of the main body of the lake is fairly regular. That of the north arm from Gypsum point to Rae is broken into many bays and shows numerous outcrops of Palaeozoic (Ordovician) rocks. Along the east shore of the north arm and around the margin of the east arm the shoreline is so irregular that even the largest available maps (4 miles to the inch) can scarcely indicate the thousands of bays, channels and islands. The map of McLeod and Christie bays, fig. 7 (folding out at back of publication), gives some indication of the complex topography of these new precambrian areas.

The length of the lake shoreline has been measured, from maps of 4 and 6 miles to the inch, at approximately 1900 miles. The shoreline of the islands

measures about 1,000 miles. Such measurements obviously do not follow the minute irregularities of the shoreline. The shore development (ratio of actual shore length to the perimeter of a circle of area equal to that of the lake) is approximately 5.1. This indicates a high degree of irregularity in shoreline; it

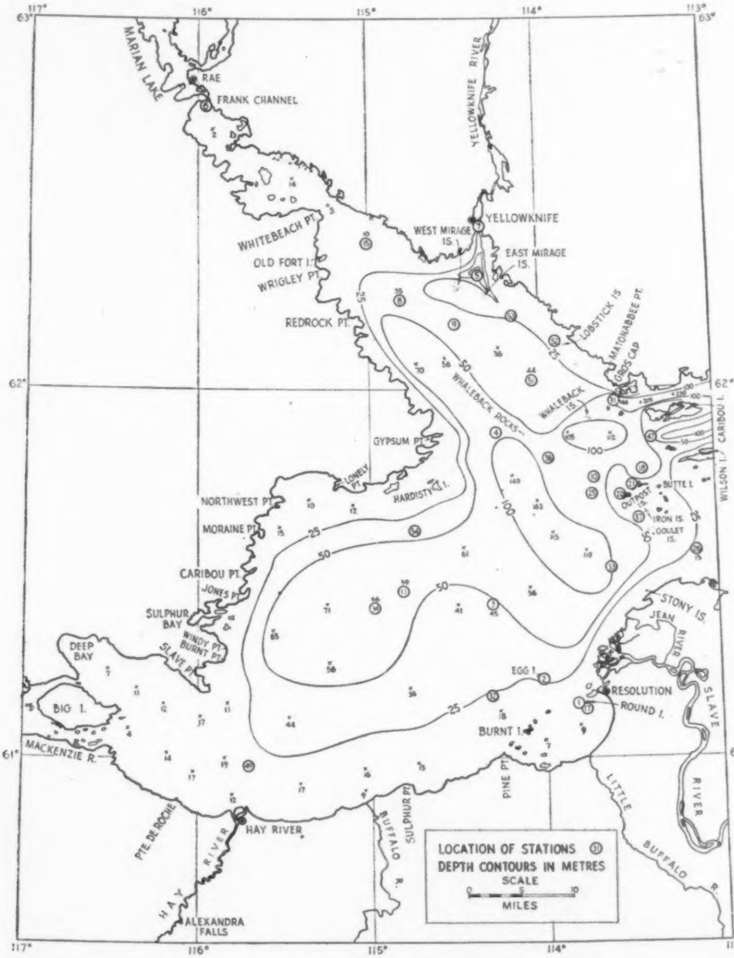

FIGURE 5. Map of the main part of Great Slave lake (west of 113°) showing depth contours and location of stations for physical and chemical observations.

cannot indicate, however, that one part, the east arm, has a much greater shore development than the remainder of the lake.

The distribution of shore types has not been classified or mapped in detail. In general the south shore from the Slave river to the Mackenzie is much exposed.

Sand beaches (fig. 8*a*) predominate but many stretches of stone and boulders are also found. Sand beaches are less common on the northwest shores, where bed rock is often exposed and boulders are very frequent. The smooth sloping rock

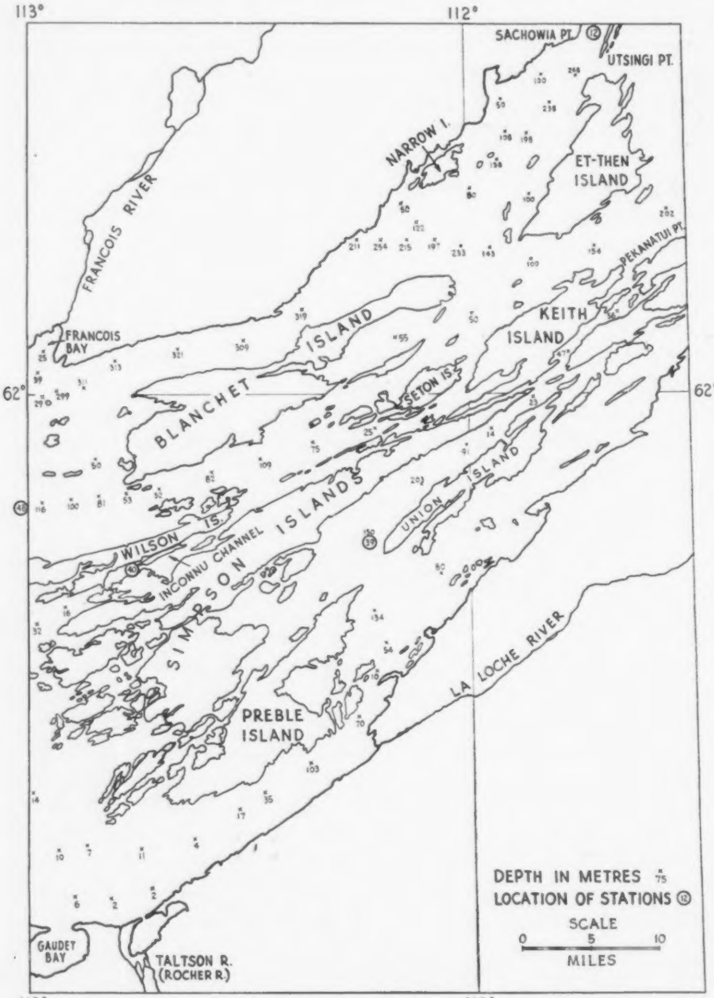

FIGURE 6. Map of the "Islands Section" of Great Slave lake showing depths and observation stations.

shores of the Yellowknife region are illustrated in fig. 8*b*. In the east arm the precambrian shores are more rugged with many cliffs (fig. 8*c*), boulder beds and few sandy areas. While exposed shores of sand or rock leave little hold for

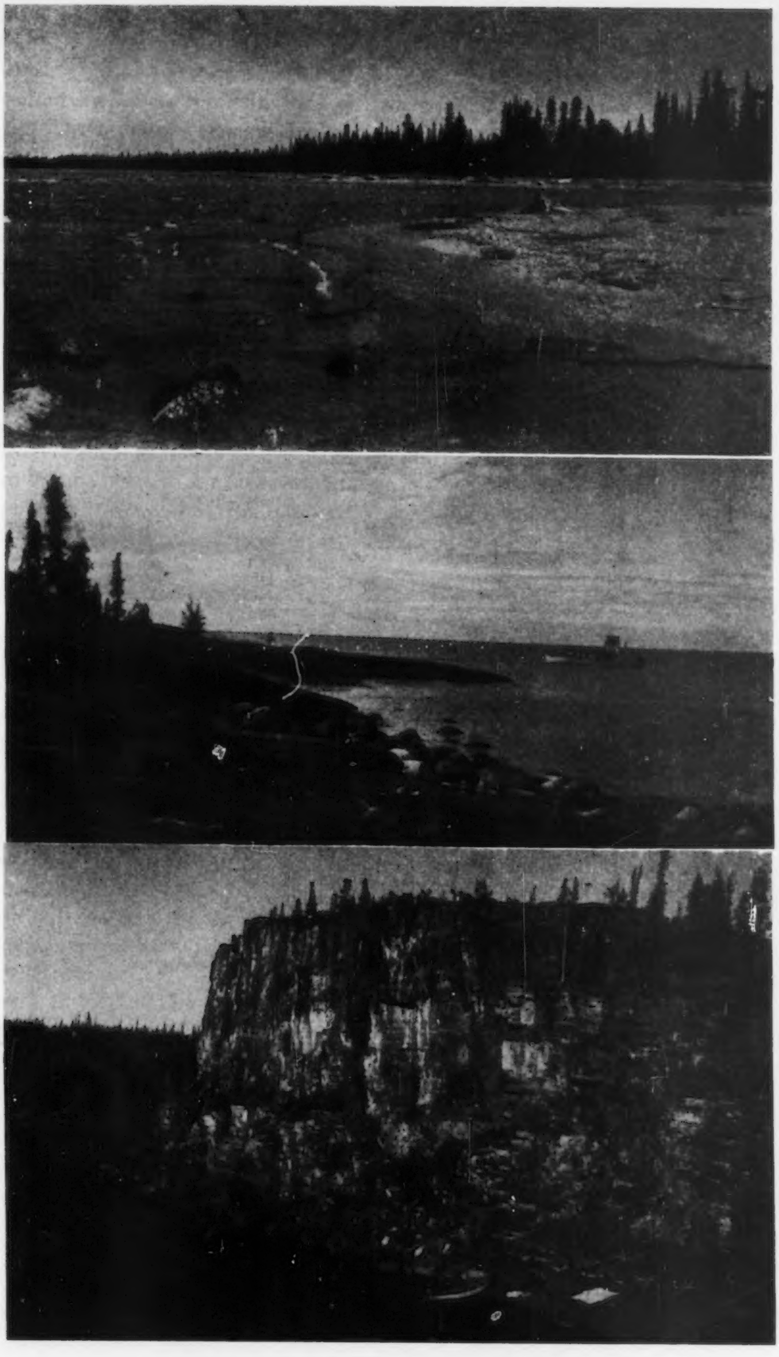

FIGURE 8. Typical shorelines at Great Slave lake.
a. Low shore at Big Buffalo river, typical of the Mackenzie lowlands.
b. Rocky precambrian shore of Yellowknife bay.
c. Cliff at Gibralter point, McLeod bay.

rooted aquatic vegetation, there are in the east arm and elsewhere numerous channels and well-protected small bays in which warmer water, a rich humus bottom and a rich growth of aquatic plants may be found. Minnows and young fish are often found in large numbers in these sheltered environments.

Area

The area of the lake has been determined as 10,500 square miles (27,200 sq. km.) and this includes islands totalling about 700 square miles. Thus the islands occupy about 7% of the lake and nearly 30% of the east arm. Since the east arm differs in many ways from the remainder of the lake it has been convenient to consider the line 113° as a boundary. (A line from Gros Cap to Rocher river past the west ends of Caribou and Wilson islands would be a more natural but less easily defined boundary). Thus the main lake to the west has a water area of about 7,500 square miles. The water area of the east arm is 2,300 square miles and this may be further sub-divided into the "islands" region 880, Christie and adjacent bays 820, and McLeod bay, 600 square miles.

Depth

Great Slave lake is comparatively deep in the central part and extremely deep in the east arm. An erroneous impression of shallowness has been obtained by those who cross the lake along the south shore from the Slave delta to the source of the Mackenzie river. The maximum observed depth in the central region is 163 metres (535 feet) and in the east arm 614 metres (2,015) feet. Extensive sounding was carried on to delimit the potential fishing grounds and to obtain data required in studies of heat and oxygen exchanges. Field operations were greatly facilitated by the use of a 60-foot barge, which provided laboratory and living accommodation. A 35-foot motor boat the ***Investigator*** was also constructed for this work, fig. 9.

Soundings in shallow water were made with tarred cotton metre-lines and in deep water with an eighth-inch stainless steel cable and a recording meter-wheel. A description of this equipment has been published by the writer (Rawson 1947a). Series of soundings were run across the main lake and bays in sufficient number to plot approximate depth contours. Many depth measurements were coincident with dredgings, net sets or temperature observations. When the survey began in 1944, detailed hydrographic surveys were available only for the inshore area between the Slave delta and the source of the Mackenzie. From 1945 to 1948 detailed surveys of the shore waters were made from the Mackenzie river to Gypsum point and in Yellowknife bay. These records have been made available through the kindness of the Hydrographic Service, Department of Mines and Resources, Ottawa. They have been used to correct the position of the 25 metre contour in some areas in the map, fig. 5.

Depth distribution in the *main lake* is shown by the contours for 25, 50 and 100 metres in fig. 5 and by the values in table II. The mean depth has been determined as 41 metres. About 45% of the main lake is less than 25 metres in depth. Much of this shallow water is found along the south shore, in the large

bay near the outlet and in the last 50 miles of the north arm. The 25-metre contour comes close to shore off the Slave delta and along the west shore between Gypsum to Redrock points. The area from 25 to 50 metres in depth comprises

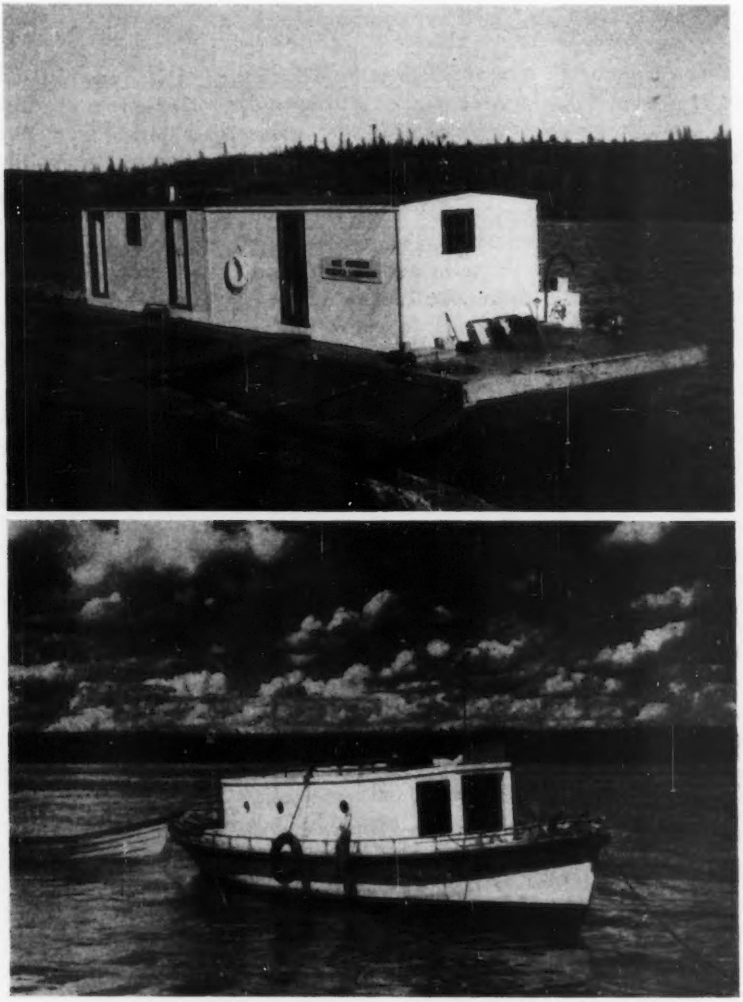

FIGURE 9. Laboratory barge and motor boat *Investigator* constructed for field work on Great Slave lake.

a further 26% of the main lake. The 50-metre contour marks the approximate outer boundary of the fishing grounds since the fishermen rarely set nets beyond this depth. The main area of 50 to 100 metres depth extends from near the

TABLE II. Areas, mean depths and percentage areas of depth zones in sections of Great Slave lake.

	Main lake, West of 113°	East Arm			
		"Islands" section	Christie and adjac. bays	Christie bay alone	McLeod bay
Area km² (sq. mi.)	19,400 (7,480)	2,290 (885)	2,120 (820)	1,510 (582)	1,590 (615)
Mean depth m.	41	76	199	249	120
Depth zones	Per cent	Per cent	Per cent	Per cent	Per cent
0 - 25 m	45.3	52.0	20.8	10.9	14.6
25 - 50 m	25.5	33.0			
50 - 100 m	23.3	16.4	17.4	12.0	30.6
100 - 200 m	5.3	11.9	20.5	20.4	40.3
200 - 300 m	0.6	6.0	16.3	21.6	14.8
300 - 400 m	....	3.7	11.3	15.8	....
400 - 500 m	....	....	6.5	9.1	....
500 - 600 m	....	....	5.6	7.9	....
600 - 614 m	....	....	1.6	2.3	....

Slave delta to Red Rock point in the north arm and has a club shaped expansion toward Jones and Windy points in the western part of the lake. A considerable area more than 100 metres deep lies in the centre of the lake and a smaller one toward Gros Cap. Small areas over 100 metres in depth occur in the lower part of Yellowknife bay, in the Hearne channel near Gros Cap and south of Caribou island. Another small area over 200 metres in depth is found in the Hearne channel. Since these small areas of deep water are not characteristic of the main area they have been disregarded in the general statement above, that the maximum depth observed in the main lake was 163 metres, at a point about 16 miles due west of the Outpost islands.

The "*islands*" *section*, from 113° east to Et-then island includes seven major and countless small islands, fig. 6. For purposes of calculation its eastern limit has been defined as Taltheilei narrows and a line from Utsingi to Pekanatui points across the eastern part of Et-then island. The water area in this section is 885 square miles, and the islands about 480 square miles. Many soundings have been made in the Hearne and Hornby channels. The latter is the route from Taltson river to Christie bay, passing south of Preble island, north of Union and south of Keith to emerge at Pekanatui point. Only a few soundings have been made in the Inconnu channel and the area south of Blanchet island. It was obviously impossible to sound all the small inlets and channels. However, rough depth contours were drawn to obtain the mean depth (76 metres) and to indicate the approximate distribution of depth zones as recorded in table II.

Representative soundings, mostly in the deeper water, are indicated in fig. 5. The Hearne channel is deep throughout its length running from 200 metres south of Gros Cap to 320 north of Blanchet island and 240 north of Et-then island. Much of Hornby channel is shallow but a small area southeast of Preble island exceeds 100 metres and a larger area north of Union island exceeds 200 metres.

Christie bay (fig. 7) is of special interest because of its extreme depth. A depth of 440 metres was discovered in a reconnaissance by canoe in 1944 so, in 1946 we came provided with steel cable and meter-wheel for sounding. Using the harbour at Pearson point the large bay was rather thoroughly sounded in the years 1946 and 1947. The main part of the bay is about 65 miles long and 10 miles wide. Near its centre is found an area of about 13 square miles which exceeds 600 metres in depth. The deepest sounding was 614 metres (2,015 feet).

Associated with Christie bay there are several water areas like Wildbread bay to the north and Portage inlet to the south which are hardly to be considered as part of the bay. The problem of expressing the areas of the depth zones has been met by calculating in two ways, table II. The section "Christie and adjacent bays" (820 square miles), includes all the water areas east of the above-mentioned line from Utsingi to Pekanatui points. Note however that Stark lake just east of Snowdrift enters the lake by a short rapids and is thus not considered part of Great Slave lake. The section "Christie bay proper" excludes Wildbread bay and the Gap and is bounded on the south by a line from the southeast corner of Et-then island to Redcliff and from Redcliff to Pearson point. The region thus defined has an area of 582 square miles. The depth contours show that Christie bay has a reasonably symmetrical basin in spite of its rugged surroundings. It is most precipitous north of Pearson point where it drops to 500 metres in 1.5 miles. The deep water area is extensive. About 60 square miles exceed 500 metres and 200 square miles are deeper than 300 metres (980 feet). Wildbread bay lies in the middle of the Pethei peninsula between Christie and McLeod bays. It is separated from the Lost channel of McLeod bay by a narrow neck only 50 yards across and less than 10 feet above lake level. It is thus probable that the water from McLeod bay has been connected through this channel to Christie bay in fairly recent times.

McLeod bay (fig. 7) connects with Hearne channel at Taltheilei narrows. This neck is about 500 yards wide, comparatively shallow, and a strong current passes through it to the south. This would suggest that McLeod bay might be considered as a separate lake and, as will be seen later, other physical and biological observations tend to justify this distinction. The bay is 90 miles in length, about 10 in width and its area is 615 square miles. It has thus an area nearly equal to that of Christie bay but its depth is only half as great. About 45% of the bay is deeper than 100 metres, about 40% between 100 and 200 and about 15% deeper than 200, table II. The maximum observed depth was 280 metres, at a point close to the centre of the bay. As in Christie bay the depth contours tend to be fairly symmetrical and no great bottom irregularities were discovered. It was noted that great depths were not found near shore in the

places where high cliffs or escarpments came close to the water's edge (see map, fig. 7).

VOLUME

From the areas and mean depths of the sections of the lake listed in table II the total volume of the lake has been calculated as 1.58×10^{12} cubic metres. The total water area is 254,000 square kilometres thus the mean depth of the whole lake is 62 metres. Since the lake includes three rather distinct basins the latter figure is of little practical value. Of much greater significance are the volumes of the three chief basins and the relative volumes of their depth strata shown in table III. Nearly 50% of the water volume of the main lake lies above the 25-metre and about 75% above the 50-metre level. Thus most of the water in this area is subject to some heating and light penetration. McLeod bay has less than half its volume above the 50-metre level and Christie bay less than 20%. Indeed 65% of the volume of Christie bay lies below the 100-metre level and is thus subject to extreme conditions of cold, darkness and pressure. The much-divided, islands area and the bays adjacent to Christie bay have not been included in table III since calculation of the volumes of their depth strata can have little meaning. Such calculations can be made from data in table II if they are desired.

TABLE III. Total volume and percentage volume of depth strata in three parts of Great Slave lake.

	Main lake (west of 113°)	Christie bay proper*	McLeod bay
Volume 10^6 cu. m.	795,000	379,000	191,000
Percentage of total volume represented by depth strata			
0 - 25 m	49.1	....	....
25 - 50 m	26.3	....	....
0 - 50 m	....	18.8	45.0
50 - 100 m	22.3	16.4	34.1
100 - 200 m	2.3	26.8	16.5
200 - 300 m	....	18.4	4.4
300 - 400 m	....	10.8	....
400 - 500 m	....	5.8	....
500 - 600 m	....	2.9	....
600 - 614 m	....	0.06	....

*Not including Wildbread and other adjacent bays (fig. 7).

The rate of inflow in relation to the volume of the lake is of some importance in the accumulation of nutritive materials and the replacement of those used in harvesting the lake. The volume of Great Slave lake has been calculated as 1,580,000 million cubic metres. The average annual rate of inflow from all rivers

has been estimated as 143,000 cubic feet per second. This is equivalent to an inflow of 12,800 million cubic metres per year. Thus the annual inflow from all sources is about 1/125 of the lake volume. Most of the inflow to the main lake comes from the Slave river which has an average annual rate of flow of 118,000 c.f.s., equivalent to 11,200 million cubic metres per year. This represents one-seventieth of the volume of the main lake (west of 113°).

Water Levels

In discussing the geological formation and development of the lake, in an earlier section, it was pointed out that the lake level appears to have subsided at least 300 feet from its early post-glacial condition. It is believed that the lake has been receding slowly in recent years. Mission "island" near Fort Resolution is now more accurately described as a peninsula. Historical evidence of recent lowering of the lake has not been investigated.

The present level of Great Slave lake is listed officially as 495 feet (162 m.). It is subject to some fluctuation both seasonal and annual but the amount of change is much less than that observed in Lake Athabaska where seasonal variations of as much as 8 feet occur (Rawson 1947). Daily records of levels at Fort Resolution and Yellowknife for the 11-year period 1938 to 1948 have been examined. The seasonal change follows a fairly constant pattern from year to year. The maximum usually occurs in late July or early August, after which the water drops steadily to a low level in October. It then recedes slowly to a minimum, usually reached during April. In May and June the level rises steadily toward the midsummer maximum. The total annual fluctuation may reach or exceed 2.5 feet, but in the period 1938 to 1948 it averaged 1.6 feet.

The variation in level over the 11-year period was marked by gradual trends rather than sudden or erratic changes. The high water level increased slightly from 1938 to 1940, then decreased until 1945 and increased progressively from 1945 to 1948. The maximum level recorded at the Yellowknife station was 494.7 feet on August 30, 1948. The minimum low water level was 491.5 in April 1945, a total range of 3.2 feet. Changes of this magnitude did not occur in any single year.

Observations of lake levels at Fort Resolution frequently showed variations of as much as 5 inches associated with strong winds. Great stretches of mud flats may be exposed and reflooded again in a few hours. It is probable that detailed studies in this area would detect periodic oscillations in level set up by the action of winds.

Comparison with Other Large Lakes

Great Slave lake with an area of 10,500 square miles is the fifth largest on this continent. Its area is about one-third that of lake Superior, one-half that of Huron or Michigan and only slightly less than that of Great Bear. Its depth of 2,015 feet (614 m.) is apparently the greatest for any lake on the continent. Crater lake, Oregon, has a small area about 2000 feet deep, lake Superior has a

maximum of about 1,300 feet, lake Michigan 870 and lake Huron 730 feet. Although Great Slave lake is very large, there are, in other parts of the world lakes which are much larger. Lake Baikal in Siberia and Tanganyika in Africa have areas of about 13,500 square miles. But Tanganyika is more than twice and Baikal nearly three times as deep as Great Slave.

Because of the peculiar shape and distribution of water areas in Great Slave lake, simple figures of depth and area may be somewhat misleading. The "main" or open part of the lake has an area of 7,500 square miles and is about 530 feet deep. Lake Ontario has similar area and depth, although it lies in very different geographical surroundings. The very deep water of Great Slave lake is characteristic only of Christie bay which, at least for purposes of physical calculation, must be considered as a separate unit. McLeod bay is even more isolated and very different from the remainder of the lake.

Noteworthy features of Great Slave lake are the large number of islands and the tremendous development of the shore line. Its shore development of more than five is probably unique among very large lakes. Here again the condition of great insulosity and high shore development are mostly found in the east arm rather than the lake as a whole.

TEMPERATURE

Surface Temperature

Surface temperatures from 1.3 to 19.5° C. have been recorded during the four seasons of observation on Great Slave lake. The several hundred readings show great variation both with time and location. They represent the combined result of seasonal change, diurnal cycles, variation in wind intensity, lake currents and the effect of river inflow. It is usually difficult or impossible to distinguish the causal factors but a sorting of the data provides illustrations of most of these effects.

The *seasonal trends* in surface temperatures in different parts of the lake have been illustrated by sorting some 300 readings into five groups according to locality and plotting them on a time scale June to September, in fig. 10. The curves illustrate the general trend in each of the five areas while the spread of individual readings suggests something of the limits of daily and local variation.

To consider first the offshore readings in the main lake, the temperature at June 15 is about 3° C. rising slowly to 5° early in July and 10° by July 18. The average surface temperature stays above 10° for two months and lies between 13 and 14° for about half of this time. Surface cooling begins about the third week in August and the average temperature falls below 10° by the middle of September.

The inshore area is here considered as the region within three miles of the shore. In the main lake inshore surface temperatures are generally above 10° by June 15. The trend throughout the season is fairly uniform with midsummer temperatures about 15° and cooling to 10° about September 15. Readings well below the curve in the first month of observation are usually attributable to winds

blowing cold water inshore or to late break-up of ice as in 1947 when the main lake opened up between June 20 and 26.

The region of the Slave delta is a special inshore area in which the surface temperatures are usually about one degree below that of the inflowing river. Here temperatures of 12° are found by June 8 and 15° by July 1. If the trend curve for the delta area is superimposed on that for the remaining inshore region,

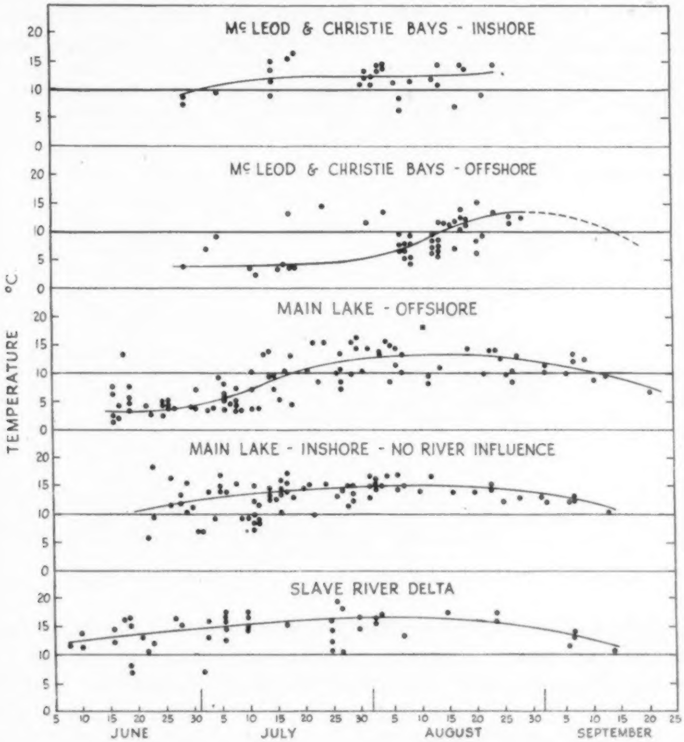

FIGURE 10. Seasonal trends in surface water temperatures in various parts of Great Slave lake.

it will be found that the delta waters are about 3° warmer in June and 2° warmer throughout the remainder of the summer season.

The surface temperature trend in the open water of McLeod and Christie bays follows a course very like that of the main lake but with a lag of approximately one month. It will be shown later that McLeod bay is covered with ice for about one month after the break-up in the main lake. We have no September data with which to follow the cooling in McLeod and Christie bays but climatic considerations are similar in both areas and the time of spawning of fish in the

east arm suggests that cooling is at least as early as in the main lake. For these reasons the trend curve is extrapolated as a broken line in fig. 10. It appears that the "summer" season in McLeod and Christie bays is of little more than one month duration and thus about one-half as long as that of the main lake. A few high temperatures, 11° to 14°, are recorded from the open water of McLeod and Christie bays from July 15 on. These were observed on very calm hot days when, in the absence of wave action, the surface water warms very rapidly.

The inshore observations in McLeod and Christie bays show a trend similar to that of the main lake but with the average temperature remaining about 2.5° lower than that of the main lake.

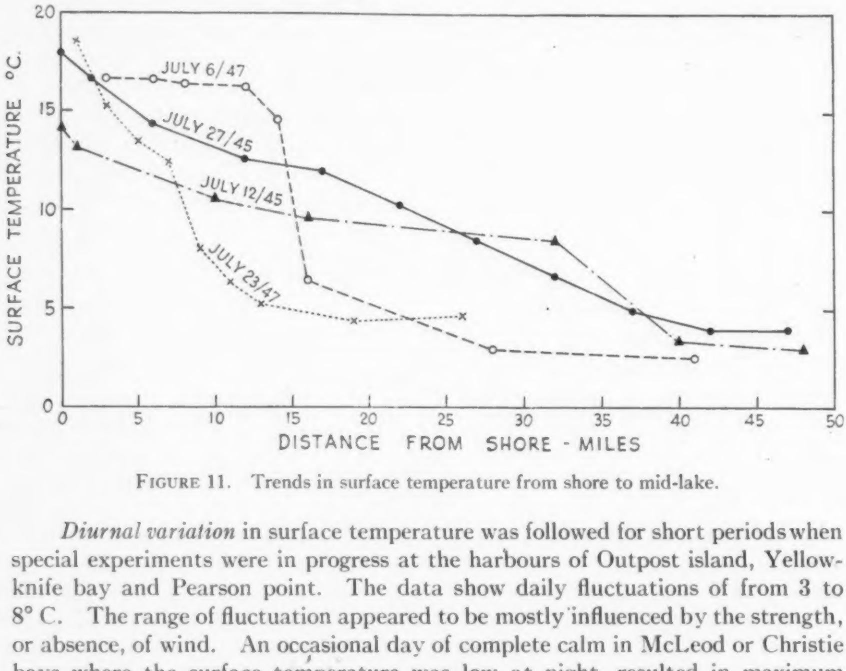

FIGURE 11. Trends in surface temperature from shore to mid-lake.

Diurnal variation in surface temperature was followed for short periods when special experiments were in progress at the harbours of Outpost island, Yellowknife bay and Pearson point. The data show daily fluctuations of from 3 to 8° C. The range of fluctuation appeared to be mostly influenced by the strength, or absence, of wind. An occasional day of complete calm in McLeod or Christie bays where the surface temperature was low at night, resulted in maximum temperatures in late afternoon as much as 8° above the "normal". Under such circumstances vertical temperature series and bathythermograph traces frequently showed a drop of 3° to 5° between the surface temperature and that at a depth of two metres. Such days or half-days of complete calm were observed, but much less frequently, on the main lake. The more usual condition was a breeze or wind which kept the upper layers circulated and limited the diurnal changes in surface temperature to 2° or less.

Inshore and offshore gradients in surface temperature were often followed by making observations at regular intervals, a practice which was followed on most of the longer boat trips. Selected curves illustrating the decline in temperature from shore toward the open lake are plotted in fig. 11. That for July 12,

1945, begins at Yellowknife, follows out through the centre of Yellowknife bay and south into the main lake to the deep water west of Outpost island. There was a gradual decline in temperature from 14° at Yellowknife to 8.5° west of Gros Cap, then a pronounced drop to 3° in passing from the warmer north arm into the central part of the lake. The remaining three curves, for July 27, 1945, July 6 and 23, 1947, are for series which begin at the Slave delta and run north to the vicinity of Gros Cap. In these the high inshore temperatures are exaggerated by the effect of warm water from the Slave river.

The generally observed decrease in surface temperature from shore outward is caused, presumably, by two factors. The inshore water heats more rapidly because it is shallow (heat may be reflected from the bottom) and the heat is not lost by circulation into the depths. Also the offshore area is more exposed to

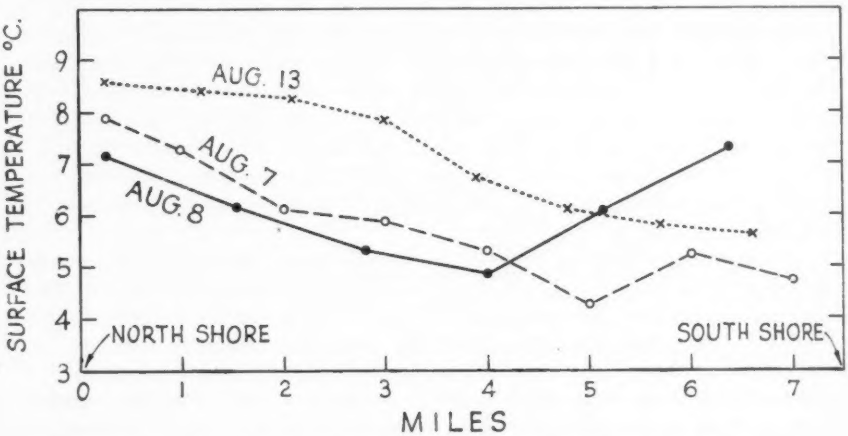

FIGURE 12. Surface temperatures in three sections across McLeod bay, August, 1945.

wind action and circulation is thus more active. Three sets of surface temperature observations across McLeod bay in August, 1945 (fig. 12) provide interesting illustrations of the effect of wind on surface temperature. On August 7, after winds from the north, the surface temperature declined from 7.9° near the north shore to 4.7° near the south. On August 8, a day of complete calm, the surface temperature dropped from 7.1° at the north to 4.9° near the centre and back to 7.3° near the south shore. On August 13, again after winds from the north, the temperature decreased from 8.6° at the north to 5.6° near the south shore. Apparently, on August 7 and 13, mixing of water near the exposed south shore destroyed the effect of inshore warming which was observed at both shores on August 8.

The *temperatures of inflowing rivers* are of interest in relation to their effect in warming the adjacent lake areas. Several observations have been recorded for the Slave, Hay, Buffalo and Taltson rivers. The Slave river varied from 12.5° C. in early June to 18.5° in late July and back to 12.0° on September 14. The other

smaller rivers ranged from 13° to 20°, the latter maximum in the slow water near the mouth of the Buffalo river on August 4, 1944. In most cases the surface temperature of the river near its mouth was from one to two degrees above the prevailing inshore surface temperature of the lake in that vicinity.

Deep Temperatures

Observations of temperatures at various depths were made with reversing thermometers attached to water bottles which took samples at the same time for chemical analysis. In 1947 and 1948 bathythermographs were used at all stations. These instruments effected a tremendous saving of time and consequently allowed much extension of observations. The continuous vertical record of temperature obviated the need for interpolation between successive reversing thermometer records and demonstrated also that considerable errors could be made in such interpolations even between fairly closely spaced observations. When the bathythermograph was in use reversing thermometer readings were taken only at those levels from which water samples were desired and from depths beyond the lower range of the instrument. In 1947 a "shallow" bathythermograph, recording down to 175 feet, was used. This covered the region in which the more pronounced changes in temperature occur, but the deep instrument recording to 450 feet was used in 1948 and found more suitable for work in a large lake.

About fifty stations for temperature and chemical observation were established during the four-year period. They have been numbered serially and their locations are indicated on maps, figs. 5, 6 and 7. Many of these were occupied only once or twice but selected stations were visited frequently for seasonal data and one, station 31 off Gros Cap, was used at weekly intervals over the three-year period, 1946 to 1948. In addition to the regular stations, bathythermograph and Secchi disc records have been taken at about 160 points at which no chemical analyses have been made.

The morphometric differences in the various parts of the lake as described above are paralleled by differences in their thermal conditions. Thus it will be necessary to treat each section separately. The main lake will be considered first, then the islands section, then Christie and McLeod bays.

The Main Lake

Temperature data for the main lake are listed in tables IV to XI. The most complete seasonal records are for station 31, tables IV, V and VI, for the years 1946, 1947 and 1948. This station was established in 1946 after the first two years of the investigation had been devoted to obtaining information from all parts of the lake. Observations from various open water stations are recorded in table VII, those from the north arm in table VIII and from Yellowknife bay in table IX. Stations near the Slave river delta and west of Outpost islands are recorded in table X and observations at many shallow stations around the lake in table XI.

TABLE IV. Limnological observations at station 31, off Gros Cap, 1946.

	June 17	June 23	June 30	July 7	July 14	July 21	July 28	Aug. 3	Aug. 19	Aug. 27	Sept. 2
					Temperature ° C.						
Air	7.6	6.6	9.0	12.0	9.0	15.5	16.2	17.9	18.0	15.0	17.0
Surf.	2.0	2.5	4.0	4.9	9.6	10.5	10.8	13.2	14.6	8.6	11.3
5 m	...	...	...	...	5.2	9.0	10.2	9.5	...	6.3	...
10 m	1.9	2.4	3.9	4.3	4.8	7.9	9.4	8.0	10.5	5.7	11.1
15 m	...	...	...	...	...	5.3	7.6	6.8	...	...	...
25 m	1.9	2.3	3.8	...	4.2	...	6.2	6.8	8.3	...	11.4
50 m	1.2	2.4	3.6	3.6	4.0	5.1	4.9	4.4	6.0	4.5	8.5
Bott. 140	2.1	2.7	3.4	3.6	3.8	4.2	4.8	4.8	4.7	4.4	4.8
					Dissolved Oxygen m.g./l.						
Surf.	11.7	11.7	12.8	11.6	10.9	11.1	10.4	10.4	9.9	11.1	10.3
10	12.1	12.0	12.7	11.6	11.7	11.1	10.2	11.0	10.1	11.2	10.7
50	12.3	12.1	12.5	11.7	11.6	11.1	10.7	11.0	10.3	11.0	11.3
Bott.	12.3	11.9	12.5	11.7	11.3	11.3	11.2	10.9	10.4	11.4	11.3
					pH						
Surf.	7.9	...	7.7	7.7	7.9	7.8	8.0	...	7.7	7.8	7.8
Bott.	7.8	...	7.6	7.6	7.6	7.6	7.4	...	7.5	7.6	7.8
					Secchi disc m.						
	5.0	5.3	5.5	...	7.3	4.5	3.5	3.8	5.0	3.5	3.6

TABLE V. Limnological observations at station 31, off Gros Cap, 1947.

	June 25	July 3	July 9	July 16	July 23	July 29	Aug. 5	Aug. 12	Aug. 22	Aug. 27	Sept. 2	Sept. 9	Sept. 21
						Temperature ° C.							
Air	4.1	9.8	8.5	10.0	10.3	...	...	9.8	9.0	11.5	12.0	12.5	0.0
Surf.	2.2	4.0	3.5	5.8	8.5	9.4	8.8	8.2	10.0	10.5	10.7	9.5	6.9
5 m	...	...	...	...	5.7	9.3	8.6	7.6	...	10.1	10.4	...	...
10 m	2.1	3.9	3.3	...	5.3	9.0	5.2	5.3	...	9.4	10.2	...	...
15 m	...	...	...	...	5.0	7.3	4.4	5.1	...	8.2	8.9	...	...
25 m	2.0	3.9	3.2	5.2	4.6	4.9	4.1	4.8	7.7	6.2	6.8	9.1	7.1
35 m	...	...	...	...	4.4	4.6	4.0	4.0	...	5.3	5.4	...	...
50 m	2.6	4.3	3.4	4.9	4.3	4.4	3.9	4.0	5.3	4.8	5.0	8.6	4.5
140 m	3.8	4.6	3.2	4.9	4.3	...	3.9	3.7	4.0	4.1	4.3	4.5	4.1
						Dissolved Oxygen mg./l.							
Surf.	11.3	11.1	13.0	12.4	11.7	...	11.1	11.6	11.3	10.9	11.5	11.0	11.9
25 m	10.9	12.0	13.1	12.4	12.3	...	11.8	12.3	11.6	11.0	11.3	10.7	11.1
40 m	10.3	10.9	12.9	12.4	12.3	...	12.2	12.1	11.6	11.6	11.1	10.7	12.2
140 m	11.4	10.6	13.0	12.3	12.3	...	12.2	12.3	11.7	11.6	11.0	11.6	11.4
						pH							
Surf.	8.4	7.6	7.9	...	...	...	8.0	7.9	...	...	...	...	...
50 m	7.6	7.6	7.9	...	...	...	7.8	7.8	...	...	...	...	...
140 m	7.3	7.5	7.8	...	...	...	7.8	7.8	...	...	...	...	...
						Secchi disc m.							
	...	7.4	4.9	8.0	5.0	...	3.2	2.2	3.5	4.0	5.0	3.5	2.0

TABLE VI. Limnological observations at station 31, off Gros Cap, 1948.

	June 25	July 1	July 8	July 14	July 22	July 31	Aug. 6	Aug. 11	Aug. 26	Sept. 11	Sept. 13
					Temperature ° C.						
Air	8.2	8.0	12.2	16.2	19.0	11.0	18.0	20.2	9.5	1.4	...
Surf.	3.8	3.9	7.8	14.0	16.0	10.3	14.5	18.3	9.8	8.9	9.5
5 m	...	...	5.3	8.6	15.4	8.2	12.7	14.1	9.6	8.8	9.4
10 m	3.8	3.9	4.9	6.7	13.0	7.0	11.5	11.4	9.4	8.7	9.2
15 m	...	...	4.5	5.5	6.7	5.5	10.3	11.0	8.7	8.6	8.8
25 m	3.8	3.9	4.3	4.3	4.9	4.9	8.0	8.7	8.0	8.5	7.9
50 m	3.8	4.2	4.1	4.2	4.2	4.6	3.9	5.5	7.7	6.7	6.7
100 m	3.9	4.2	4.2	3.9	4.5	4.2	3.9	4.6	5.0	5.0	5.0
140 m	...	4.1	3.6	3.6	4.2	3.9	3.9	4.2	4.2	4.7	...
					Dissolved Oxygen mg./l.						
Surf.	10.9	12.1	11.4	10.3	9.0	10.2	9.4	9.0	11.1	11.1	...
25 m	10.6	12.3	12.1	10.9	10.8	11.3	10.3	9.7	11.6	11.4	...
50 m	10.4	12.1	11.9	11.0	10.5	11.4	10.8	10.1	11.3	11.6	...
140 m	10.6	12.0	11.6	11.3	11.3	11.6	11.1	10.9	10.5	12.0	...
					Secchi disc m.						
	4.5	6.5	4.5	1.3	0.7	1.3	0.5	1.0	2.0	2.0	...

TABLE VII. Limnological observations at offshore stations in the west arm of Great Slave Lake.

Sta. 3 25 m N.W. of Resolution June 26/44	Sta. 10 6 m N.W. of Outpost Aug. 1/44	Sta. 11 30 m of E. Jones Pt. Aug. 7/44	Sta. 18 3 m N.E. of Outpost July 3/45	Sta. 22 ½ m W. of Outpost July 10/45	Sta. 32 10 m S.W.W. Egg Is. June 18/46	Sta. 34 25 m E. Jones Pt. July 1/46	Sta. 38 10 m S.W. Whale-back Is. July 18/46	Sta. 25 6 m W. of Outpost July 24/45	Sta. 25 6m W. of Out-post Aug. 7/47	Sta. 25 6m W. of Out-post Sept. 6/47
				Temperature ° C.						
Air 9.4	Air 14.5	Air 17.5	Air ..	Air ..	Air 20.0	Air 8.0	Air 11.2	Air ..		
Surf. 4.5	Surf. 14.5	Surf. 13.6	Surf. 3.4	Surf. 7.0	Surf. 13.2	Surf. 3.8	Surf. 4.4	Surf. 15.5	10.1	10.0
44 m 3.9	5 m 11.8	5 m 11.7	46 m 3.7	18 m 4.6	10 m 5.8	5 m 3.2	5 m 4.4	10 m 7.7	9.8	9.9
	10 m 9.8	10 m 7.3	97 m 4.0	36 m 4.2	23 m 4.1	10 m 3.2	105 m 3.7	20 m 6.2	5.3	9.7
	20 m 5.7	25 m 4.8				25 m 3.2		30 m 5.8	4.8	8.8
	30 m 4.9	40 m 4.2				66 m 3.2		40 m 5.3	4.3	6.0
	65 m 4.3	58 m 4.0						60 m 4.4	4.3	4.4
				Oxygen mg./l.						
Surf. 8.6	Surf. 9.3	Surf. ..	Surf. 12.3	Surf. 12.0	Surf. 9.6	Surf. 11.4	Surf. 11.6	Surf. 10.9	..	..
44 m 8.7	65 m 11.0	58 m 10.9	97 m 10.6	36 m 12.0	23 m 10.4	66 m 11.1	105 m 10.9	60 m 11.4	..	..
				pH						
Surf. 7.4	Surf. 7.6	Surf. 7.7	Surf. 7.7	Surf. 7.7	Surf. 7.6	Surf. 7.6	Surf. 7.5	Surf. 7.8	..	..
44 m 7.9	65 m 7.3	58 m 7.2	97 m 7.8	36 m 7.7	23 m 7.6	66 m 7.8	105 m 7.1	60 m 7.7	..	..
				Secchi disc m.						
2.2	1.3	5.7	3.5	2.0	1.0	2.3	4.3	0.8	1.3	2.1

TABLE VIII. Limnological observations at stations in the north arm of Great Slave Lake.

Sta. 4 10 mi. E. of Gypsum Pt.	Sta. 8 8 mi. N.E. of Redrock Pt.	Sta. 9 8 mi. S. of W. Mirage Island	Sta. 15 1 mi. E. of Louise Pt.	Sta. 15 15 mi. W. of Matonabbee Pt.			Sta. 52 Off Lobstick Is.				Sta. 53 5 mi. S.E. of E. Mirage Island		
June 26/44	July 27/44	July 29/44	Aug. 28/44		July 8/47	July 29/47		July 29/47	July 3/48	July 10/48		July 3/48	July 10/48
Temperature ° C.													
Air 10.0	Air 16.6	Air 16.0	Air 14.4	Air	9.6								
Surf. 3.9	Surf. 13.5	Surf. 15.8	Surf. 13.0	Surf.	3.3	12.4	Surf.	12.0	9.0	12.5	Surf.	7.8	12.6
25 m 3.7	10 m 12.8	10 m 11.6	8 m 12.6	10 m	3.3	9.7	5 m	11.8	8.7	10.1	5 m	7.2	8.2
50 m 3.6	15 m 7.6	30 m 5.0		25 m	3.2	4.6	10 m	8.5	6.1	5.8	10 m	5.3	5.0
95 m 3.6	20 m 4.7			35 m	3.3	4.3	15 m	6.1	5.4	5 2	15 m	4.2	4.2
	35 m 4.6			50 m	3.4	..	20 m	5.8	..	..	20 m	3.9	4.2
Oxygen mg./l.													
Surf. 12.1	Surf. 9.7	Surf. 9.3	Surf. 8 9	Surf.	12.6	..							
50 m 12.0	15 m 10.7	30 m 10.3	8 m 9.1	50 m	12.7	..							
95 m 12.0	35 m 10.9												
pH													
Surf. 7.4	Surf. 8.0	Surf. 7.8	Surf. 7.6	Surf.	7.7	..							
95 m 7.4	35 m 7.6	30 m 7.4	8 m 7.6	50 m	7.7	..							
Secchi disc. m.													
2.9	4.1	4.2	0.8		3.2	..							

TABLE IX. Limnological observations at station 5, Yellowknife bay.

	June 29/44	July 14/44	Aug. 25/44	July 16/45	July 28/46	Aug. 10/46	July 29/47	Aug. 1/47
Temperature ° C.								
Air	11.2	12.8	12.5	....	11.1	17.2	16.5	3.0
Surf.	10.6	10.4	12.6	10.6	11.3	14.0	13.2	13.5
10 m	....	....	....	....	9.3	11.5	11.2	10.1
25 m	....	....	....	4.3	8.6	9.0	4.8	4.6
Bott. 63	4.6	....	7.8	4.3	5.7	6.9	4.1	4.1
Dissolved O_2 mg./l.								
Surf.	10.3	10.1	9.4	11.1	10.1	....	10.4	....
10 m	....	....	....	....	....	....	11.1	....
25 m	....	....	....	12.0	....	....	11.8	....
(B) 63	....	....	9.9	11.1	11.7	....	11.8	....
pH								
Surf.	7.8	7.7	8.0	7.8	7.9	7.7	8.0	....
10 m	....	....	....	....	....	....	8.0	....
25 m	....	....	....	7.6	....	....	7.7	....
(B) 63	....	....	7.6	7.6	7.4	7.4	7.7	....
Secchi disc m.								
	2.8	4.3	3.0	....	3.5	3.3	....	....

Table X. Limnological observations at two stations about twelve miles from the Slave River delta.

	Sta. 2 1 mi. S.E. of Egg Is. June 25, 1944	Sta. 2 June 17, 1946	Sta. 2 July 4, 1947		Sta. 33 12 mi. N. of Slave delta Aug. 2, 1945	Sta. 33 June 22, 1946	Sta. 33 July 6, 1947	Sta. 33 July 26, 1947	Sta. 33 Aug. 7, 1947	Sta. 33 Sept. 6, 1947
					Temperature ° C.					
Air	11.1	11.8	7.0	Air	18.0	...	....	....	....	....
Surf.	4.3	4.1	3.8	Surf.	16.9	4.6	12.6	19.3	13.5	11.2
10 m	3.9	4.1	4.3	10 m	11.5	4.6	10.1	7.8	9.4	11.2
30 m	3.8	4.2	4.3	20 m	8.3	4.5	4.6	4.3	8.0	11.0
				30 m	5.0	4.3	4.0	3.8	4.7	7.0
				50 m	4.9	4.1	3.7	3.8	3.8	4.8
				90 m	4.3	3.7				
					Oxygen mg./l.					
Surf.	12.0	9.4	11.3	Surf.	7.6	...	....	....	....	....
30 m	11.9	10.1	10.7	30 m	9.3	...	....	....	....	....
				90 m	9.3					
					pH					
Surf.	7.8	7.8	8.0	Surf.	7.7	...	....	....	....	....
30 m	7.7	7.8	8.0	90 m	7.4	...	....	....	....	....
					Secchi disc m.					
	1.8	2.3	2.1		1.3	0.8	0.4	0.3	0.8	0.6

In a lake so large and so irregular as to outline and depth, it is not to be expected that any single station can be chosen as typical of the whole body of water. However, station 31, off Gros Cap is somewhat centrally located and it will be profitable to consider first the thermal changes in this area. Later examination of data from outlying parts of the main lake will help to define the extent of the body of water which can be represented by conditions at station 31. In the graphs, fig. 13, selected temperature curves show the course of heating and cooling in the seasons 1946, 1947 and 1948.

In 1946 the ice left the main lake about June 5, a week or more before the average date. The first observation at station 31 was on June 17 and at that time the water was practically homothermous (1.9° to 2.1° C.), table IV and fig. 13 A. Warming was slow and complete mixture continued until about June 30 when the surface temperature was 4.0° and bottom 3.4° C. On July 7 warming was observed in the upper ten metres and by July 14 warming to 25 metres was noticeable. On July 21 a small thermocline was evident between 10 and 15 metres. Regular warming continued to August 19 at which time the temperature, 6.0° at 50 metres, indicates extensive heat penetration. Between August 19 and 27 a mass of cold water, presumably moving in from the east

Table XI. Limnological observations at various shallow water stations around the "main lake".

Station Number	Location	Date	Depth metres	Temp. ° C.			O_2 mg./l.		pH		Secchi Disc.m.
				Air	Surf.	Bott.	Surf.	Bott.	Surf.	Bott.	
1	1 mi. W. of Round Is.	June 23/44	11.0	10.2	12.1	9.1	10.5	10.3	7.3	7.3	0.15
6	Mouth of Frank Ch. N. Rae	July 6/44	1.3	18.0	14.0	14.0	..	..	7.2	..	0.07
7	Yellowknife Bay 1 mi. S. of Town	July 11/44	12.0	18.0	12.2	..	..	..	7.2	..	2.7
16	Yellowknife Bay E. of Joliffe Is.	Sept. 7/44	13.0	16.7	12.8	11.6	9.9	9.7	7.6	7.5	..
17	0.5 mi. South of Round Is.	June 22/45	7.0	..	10.9	9.3	11.4	12.1	..	..	0.3
19	E. end of Chan. Outpost Is.	July 11/45	11.0	..	7.5	4.4	12.6	12.3	8.0	7.8	3.5
21	0.5 mi. N. of Outpost Is.	July 11/45	23.0	..	10.0	6.0	12.4	11.6	7.9	8.2	1.2
7	Yellowknife Bay 1 mi. S. of Town	July 14/45	12.0	17.5	13.3	13.0	10.1	10.6	8.0	8.0	2.2
16	Yellowknife Bay E. of Joliffe Is.	July 18/45	11.0	..	13.5	11.2	9.0	9.1	7.6	7.8	2.0
23	Inner Bay Yellowknife	July 20/45	1.4	19.0	14.6	14.4	10.3	10.0	7.6	7.8	1.4
24	Inner Bay Yellowknife	July 21/45	3.0	18.0	15.4	14.0	9.1	9.3	7.7	7.8	2.0
19	E. end of Chan. Outpost Is.	Aug. 23/45	11.0	16.5	14.6	13.2	..	..	7.8	7.8	..
43	E. end of Gros Cap Chan.	June 22/46	16.0	12.0	6.0	4.8	12.4	12.9	7.8	7.7	5.3
44	Middle of Gros Cap Chan.	July 8/46	7.0	19.0	15.2	..	11.7	..	7.8	..	2.0
49	8 mi. N. of Hay River	June 19/48	20.0	..	7.8	4.2	..	..	..	..	..
54	10 mi. S.W. of Hardisty Is.	June 25/48	37.0	..	3.4	3.4	..	..	..	..	..

through the Hearne channel, changed the situation at station 31 back to temperatures comparable to those which had existed between July 14 and 21. This was obviously the result of water movement rather than cooling for on September 2 the temperatures were back to a high level. The curve for September 2 represents the highest mean temperature observed at station 31 in the three years of observation.

In 1947 the season was unusually late, the ice leaving the middle of the lake about June 26. Observations on June 25 show a characteristic curve, fig. 13 B, before the vernal circulation. Temperature from surface to 50 metres was

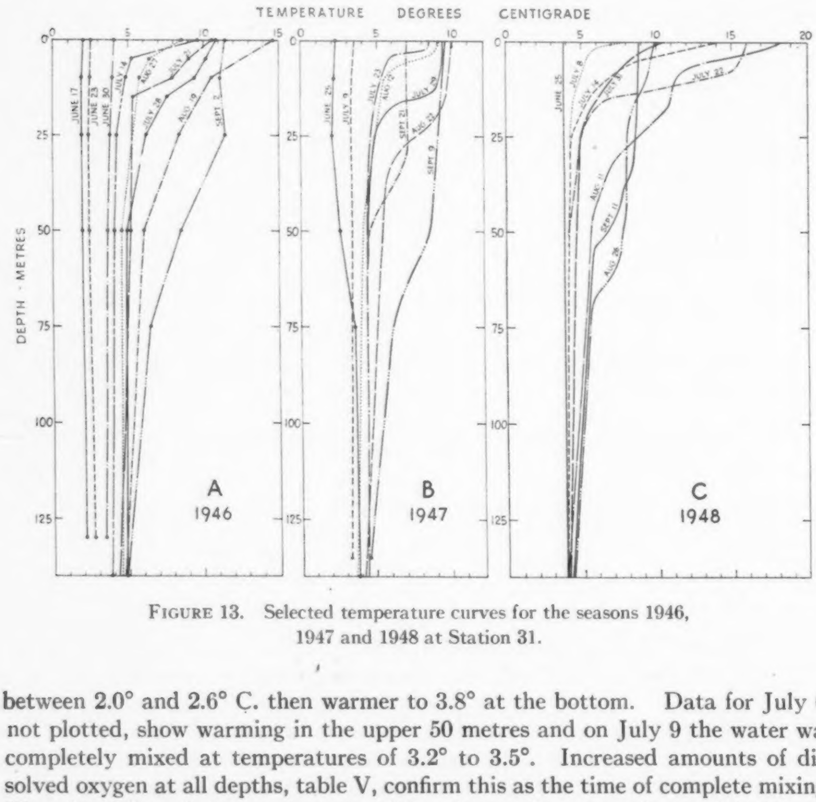

FIGURE 13. Selected temperature curves for the seasons 1946, 1947 and 1948 at Station 31.

between 2.0° and 2.6° C. then warmer to 3.8° at the bottom. Data for July 6, not plotted, show warming in the upper 50 metres and on July 9 the water was completely mixed at temperatures of 3.2° to 3.5°. Increased amounts of dissolved oxygen at all depths, table V, confirm this as the time of complete mixing. Warming followed the usual course with a thermocline appearing on July 23 and being forced deeper on July 29. But on August 12 cold water had invaded the area, as it had on August 27, 1946. By August 22 the situation was again normal and the maximum heating was observed on September 9. The curve for September 21 shows the first stage of cooling but there is evidence of a thermocline somewhere between 25 and 50 metres (the bathythermograph was not

available) and complete autumn circulation had not yet occurred. The 1947 season was short and cool but the amount of heat taken in was not much below that for 1946.

In 1948 the break-up of ice occurred about June 16. Complete homothermy was observed at 3.8° C. on June 25 and at slightly higher temperatures on June 28 and July 1. Warming of the upper ten metres was more rapid and continued to higher temperatures than in 1946 or 1947. A high degree of thermal stratification was present on July 22 when a thermocline of 8° was found between the depths of 8 and 15 metres. On July 31 cold water moved in at station 31 as it had on occasions in 1946 and 1947 and as in both years this was followed by a return of

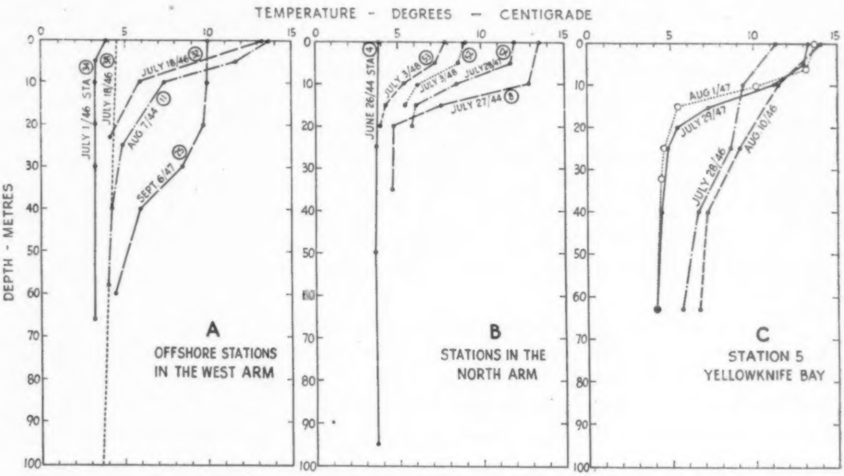

FIGURE 14. Temperature curves, Great Slave lake
A—Various parts of the main lake
B—The north arm
C—Yellowknife bay

warm water and mixing to a considerable depth. On August 6 and 11 temperatures at 25 and 50 metres were greatly increased over those at the same depths on July 22. Cooling of the surface water, shown on August 26, was accompanied by still deeper mixing. Further cooling had occurred by September 11 but the upper water was still 4° warmer than that below 50 metres.

Observations at offshore stations in the western part of the lake are recorded in table VII and selected temperature series from this table are plotted in fig. 14 A. The curve for station 34, July 1, 1946, shows homothermy at 3.2° C. except for a slight surface warming. On July 18, 1946, at station 38, the surface temperature was 4.4°, bottom 3.7° and mixing was still complete. The curve for station 11, August 7, 1944, shows simple stratification with a pronounced thermocline between 5 and 10 metres. It would appear from the shallow position of the

thermocline at this late date that warming was slow in this central area of the lake. Further seasonal observations at station 11 would be desirable. The curve for station 38 on September 6, 1947, indicates a considerable penetration of heat down to 30 metres. Records for station 2 in table X June and July 1944, 1946 and 1947 show consistently cold conditions, much like the central portion of the lake. This is somewhat remarkable in view of its proximity to the Slave delta. Observations off the delta indicate that its warming effect extends much farther north than west.

Yellowknife bay is large, very deep and somewhat isolated from the main lake by a submerged ridge across its mouth where the East and West Mirage islands emerge. Thus the temperatures in the bay are in some degree independent of conditions in the north arm. Records for station 5 in table IX and curves in graph 14, C illustrate two quite different temperature conditions in the summers of 1946 and 1947. In 1946 the curves for July 28 and August 10 show no thermocline and indicate that much heat has been mixed down to depths of more than 40 metres. This is the result of several storms in late July and early August which, our records show, were of sufficient magnitude to disrupt gill-net fishing. In 1947 at closely corresponding dates an extreme stratification and shallow thermocline were observed. No storms were recorded in that year for the period July 21 to August 3. Bathythermograph records at station 5 for July 3 and 10, 1948, indicate a warming sequence similar to that described for 1947.

Observations at two stations near the Slave delta are recorded in table X. The temperatures at station 2, near Egg island have been mentioned above as indicating that at least in the early part of the season, this station resembles the open lake and shows little delta influence. Station 33, twelve miles north of the most easterly outlet (Fisheries channel) of the Slave river, was established to investigate the effects of inflowing river water. It was soon found that much more extensive observations would be required in order to distinguish the effects of warming due to the river inflow from those of ordinary radiation and wind-caused mixture. Graph A, fig. 15 presents selected curves for station 33. On June 22, 1946, there was almost uniform mixing, with temperatures from 3.7° to 4.6° C. The remaining curves for July 6, August 7 and September 6, 1947, show thermal stratification with normal downward progress of the thermocline. In order to distinguish river warming from open lake warming these curves should be compared with those for the same dates from a point 20 miles north of the delta, graph B, fig. 15. It will be seen that on July 6 little heating had occurred at the 22 mile point, thus most of that at station 33 was due to inflow from the river. On August 7 the thermocline at station 33 was about 8 metres deeper than 22 miles out and on September 6 heating was slightly deeper and temperatures more than one degree higher at station 33. It is concluded, therefore, that much of the heating at station 33, 12 miles off the delta, is due to river inflow. By comparing the curve for September 6, 1947, for the 22 mile point, graph B, fig. 15, with that for the same date at station 25, west of Outpost island, graph A, fig. 14, it will be seen that the thermocline at station 25 is deeper and less pronounced but the amount of heating at the two stations is quite similar.

A demonstration of heating by river inflow and its gradual diminution offshore is provided by graph C, fig. 15 which shows six curves (bathythermograph tracings) for distances from 1.5 to 28 miles off the delta, on August 7, 1947. At 2.5 miles a thermocline between 30 and 32 metres shows the great depth of mixing inshore. The thermocline becomes shallower at each successive curve offshore.

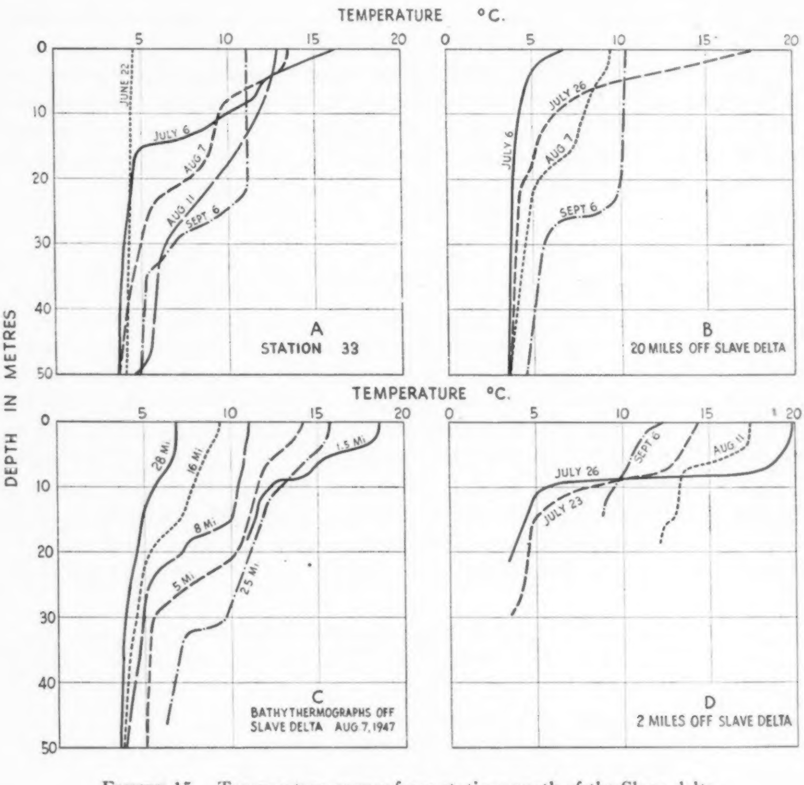

FIGURE 15. Temperature curves from stations north of the Slave delta
A—station 33, 12 miles north of the delta
B—at a point 20 miles north of the delta
C—at various distances from the delta on August 7, 1947
D—at two miles north of the delta

At 28 miles the heating is mostly confined to the upper 10 metres as it was at station 31, off Gros Cap, on this date.

To illustrate the inshore temperature conditions at the delta, graph D, fig. 15 has been constructed, showing four tracings at a point two miles from shore. On all the dates except August 11, the water was mixed down to about 9 metres and the temperature of this layer was about a degree lower than that of the river. Sharp thermoclines were found in each case, the most extensive

being that of July 26, a drop from 12° C. at eight metres to 7° at ten metres. On August 11 the thermocline was shallower and the drop of 5° occurred between the depths of 3 and 8 metres. On September 6 cooling was in progress and temperatures observed between surface and 15 metres were essentially the same as those in the offshore areas, (c.f. station 33, table X and station 25, table VIII for this date).

The above data are sufficient to show that the heating influence of the inflow from the Slave river is pronounced to a distance of 12 miles offshore and barely detectable at 20 miles. Details of the mechanics of mixing are beyond the scope of this report. In 1948 Dr. W. A. Kennedy and Mr. F. M. Atton made valuable observations in this field, using the bathythermograph to run concentric series of observations at various distances off the delta. It is hoped that work on this interesting problem will be continued.

Mean Temperatures

Because of great variation in depth of different parts of the lake, a simple mean temperature at any station becomes little more than a reflection of the relative amounts of warm shallow water and cold deep water at that location. Thus in dealing with most biological relations the mean temperature of the trophogenic stratum (0-10 or 0-15 metres) has been found more useful. For use in calculating the amount of heat entering the lake mean temperatures must be corrected for the relative volumes of the depth strata. It would also be necessary to weight the mean temperatures of different sections of the lake according to variation in the volume of individual strata. This would require much more detailed data from outlying parts of the lake than we were able to collect. Our alternative has been to assume that the centrally located station 31 represents

Table XII. Mean temperatures, station 31 off Gros Cap, 1946, 1947 and 1948.

1946		1947		1948	
June 17	1.9	June 25	2.5	June 25	3.9
" 23	2.4	July 3	4.2	July 1	4.1
" 30	3.8	" 9	3.0	" 8	4.6
July 7	4.2	" 16	5.1	" 14	5.3
" 14	4.4	" 23	5.4	" 22	6.4
" 21	6.2	" 29	8.2	" 31	5.6
" 28	6.8	Aug. 5	5.5	Aug. 6	8.1
Aug. 3	6.1	" 12	5.3	" 11	8.7
" 19	7.1	" 22	7.3	" 26	7.8
" 27	4.9	" 27	6.8	Sept. 11	7.8
Sept. 2	9.7	Sept. 2	7.0	" 13	7.7
		" 9	8.4		
		" 21	6.0		

the minimum heating in the open and deeper part of the lake. A rough estimate of the additional warming in shallow inshore areas is included at the end of this section.

Mean temperatures have been calculated from observations at station 31, using the volumes of the depth strata for the main lake (west of 113°) given in table III. The weekly temperature observations for the seasons 1946, 1947 and 1948 are listed in table XII. They have also been smoothed by threes and plotted in the graph, fig. 16. The usual course of warming appears to be from a mean of about 2° C. on June 15 to 6.5° on June 30. In mid-August of both 1946 and 1947 the mean temperatures at station 31 showed an apparent decline and

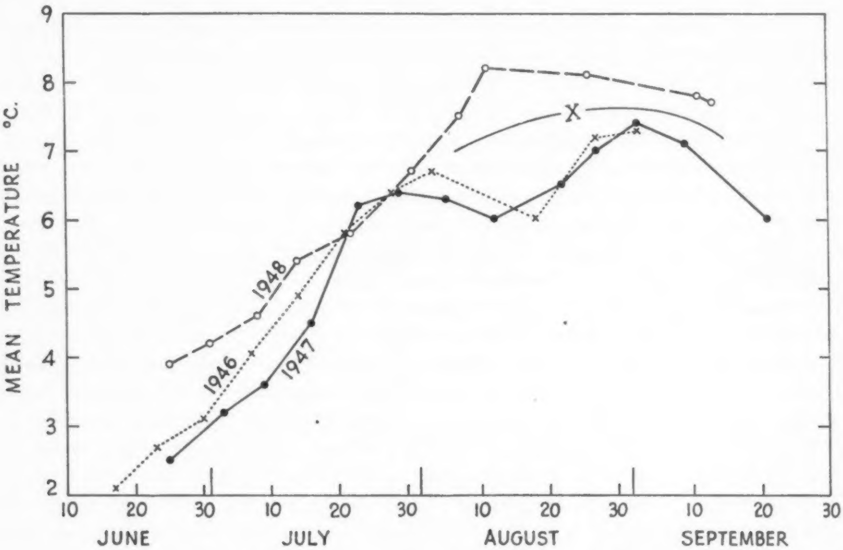

FIGURE 16. Mean temperatures at Station 31, for the years 1946, 1947 and 1948, smoothed by threes.

recovery which have been interpreted above as a movement of cold water from the east arm followed by a reverse movement of warm water from the main lake. Thus the dip in the curves for 1946 and 1947 does not represent a heat loss from the lake. This interpretation is supported by the observation that no such decline appeared in August 1948 although a brief reversal was indicated by temperatures for July 31 of that year. This drop from 6.4° C. to 5.6° and back to 8.1° is recorded in table XII but because of the smoothing is not evident in fig. 16. If, as we have assumed, water movements resulted in temperatures in August 1946 and 1947 at station 31 which are below those of the main lake proper, then it is quite possible that other water movements may have made the temperatures in 1948 unduly high. The short segment of a curve, X, in fig. 16,

is inserted as an estimate of the average rate of warming during August. It rises to a maximum of 7.6° at September 1 and is followed by fairly rapid cooling. Further observations during the cooling period would be desirable.

The mean temperature of the 0 to 10 metre stratum at station 31 has been calculated by averaging all the records for the three years in ten-day intervals. The result is a regular increase from 5° C. about July 5 to 10° at August 1, a maximum of 11.2° at August 15 then cooling through 10° at September 5 and 8° at September 15. With few exceptions, determinations of mean temperature in the 0-10 metre stratum in the middle of the west arm and west of Outpost island, follow the trend at station 31. Those in the deeper parts of the north arm and in Yellowknife bay average about two degrees higher than at station 31.

Since Yellowknife bay is more or less cut off from the main lake by the submerged ridge across its mouth, it is of interest to compare its mean temperature with that of the main lake. The bay encloses about 75 square miles of water of which 55% lies in the 0-25 metre zone, 29% is from 25 to 50 metres, 12% from 50-100 and 3% between 100 and 112 metres in depth. The mean temperatures have been calculated from five series of observations at station 5. These, in Yellowknife bay, average 2.1° warmer than those at station 31 on corresponding dates.

The additional heating in shallow areas around the main lake has been estimated by comparing the mean temperatures at all stations with those at station 31 on the same date. Observations from the Slave river delta and near the mouths of other rivers were excluded in order to distinguish between shallow water heating and the effects of river inflow. It was found that shallow heating was confined to the area outside the 25 metre depth contour and that within this area it was much more evident in the upper 10 metres stratum than in the next 15. The average excess in temperature at the shallow water stations over those at station 31 was for the 0-10 metre stratum, 2.1° C. and for the 10 to 25 metre stratum 0.4° C. Since these strata in the main lake are of almost equal volumes the average excess is 1.2° C. The volume of water outside the 25-metre contour in the main lake is 18% of the total volume of the 0-25 metre stratum. If the former fraction is 1.2° warmer than the latter, the mean for the whole stratum for the last week in August becomes 9.3° C. and the mean for the whole of the main lake is increased from 7.6° to 7.8° C.

Heat Budget

Calculation of the amount of heat taken into the lake during the summer is subject to the limitations discussed above in relation to mean temperatures. The procedure followed has been to use mean temperatures from station 31 for calculating the minimum heat gain and then to estimate within the limits of the data available, the additional heat gain in the shallow and delta areas.

Winter temperatures are not available so the total, or annual heat budget cannot be determined. However, some indication of winter temperatures is provided by the mean temperature of 1.9° C. on June 17, 1946, just after the ice

went out. Summer heat income, which is defined as the amount of heating above 4.0° C., can be calculated using the mean temperature in table XII and the mean depth of 41 metres, for the area west of 113°, table II. The highest mean temperature recorded during the three year period was 8.7° C. on August 11, 1948. This represents a summer heat income of 18,700 calories per sq. cm. of lake surface. It was suggested above that the maximum on August 11 may have resulted from an influx of warm water and thus may not represent true heat gain. The data in fig. 16 suggest that the usual peak in mean temperature is about 7.6° C., reached about September 1. This is equivalent to a summer heat income of 14,700 cal. per sq. cm. Using the same figure of 7.6° C. for the summer maximum and knowing that the winter mean goes at least as low as 1.9° C. it is clear that the total heat budget must exceed 23,400 cal. per sq. cm.

The extra heating in the shallow water zone was examined above and estimated as sufficient to raise the mean temperature of the lake from 7.6° to 7.8° C. If this is included the summer heat income becomes 15,600 cal. per sq. cm.

The heat contribution from the Slave river for the period June 15 to September 15 may be calculated from figures presented above. The volume of inflow during this period is about $4{,}700 \times 10^6$ cu. m. or roughly 0.6% of the volume of the main lake. The mean temperature of the river averages 14° or 10° above the temperature of maximum density. Thus the heat delivered by the Slave river would be sufficient to raise the temperature of the whole volume of the main lake by 0.6° C. The other smaller rivers contribute amounts of heat important locally but negligible in relation to the whole lake. It is probably not desirable to complicate the question of heat budgets by including the contributions of inflowing streams.

The summer heat income of 15,000 to 19,000 cal. per sq. cm. in the main part of Great Slave lake is in the same range as those of other lakes in temperate North America and Europe. The average for Karluk lake, Alaska, is 18,900 cal. per sq. cm. according to the data of Juday *et al.*, 1932. Ricker (1937) shows an average of about 24,000 for seven years at Cultus lake, British Columbia. In the Prince Albert Park, Saskatchewan, Waskesiu lake had 15,900 and Kingsmere 20,500 (Rawson 1936). In Wisconsin, lake Mendota had 17,500 and Trout lake 16,600. Morphometric data are not available for calculations of heat income of lake Nipigon, Ontario, but the temperature series recorded by Clemens (1924) suggest that its thermal conditions are very like those in Great Slave lake. Various lakes in southern Norway have heat incomes of similar magnitude e.g. Eikeren (Strøm 1944) 19,426 cal. per sq. cm. Lake Windermere has a summer income of 15,600 in the south basin and 20,490 in the north (Jenkin 1942).

The Islands Section

The islands section lies in an intermediate position between the main lake and the great bays of the east arm. It is composed of many long and usually deep channels. The islands divide the section so thoroughly that a generalized statement of temperature conditions is impossible. Observations at six stations

are recorded in table XIII. Stations 12, 47 and 48 which are in or near the Hearne channel show temperature characteristics like those at station 31. Station 26, off Grant point, shows the warming effect of inflow from the Taltson river and therefore resembles the stations off the Slave delta. Observations were made on July 24, 1946, at station 39, northwest of Union island, in the centre of one of the larger open areas of the islands section. The degree of warming observed at that time at station 39 was not reached at station 31 until two weeks later.

TABLE XIII. Limnological observations at stations in the "Islands" section of the east arm, Great Slave lake.

Sta. 12 Near Sachowia Pt. Aug. 14/44	Sta. 26 6 mi. N.W.W. of Grant Pt. July 30/45	Sta. 37 Near Goulet Island July 3/46	Sta. 39 1.5 mi. N.W. of Union Is. July 24/46	Sta. 40 Centre of Inconnu Ch. Aug. 6/46	Sta. 77 3 mi. off W. end Caribou Is. Aug. 6/47	Sta. 48 1mi.S.of W.end Blanchet Is. Aug. 6/47
			Temperature ° C.			
Air 11.6	Air 13.0	Air 13.5	Air 19.0	Air 19.2	Air 15.0	Air 14.0
Surf. 11.0	Surf. 16.6	Surf. 14.0	Surf. 17.9	Surf. 17.3	Surf. 11.5	Surf. 11.8
10 m 7.6	5 m 14.9	10 m 9.6	5 m 10.5	10 m 11.0	5 m 11.2	5 m 11.7
20 m 5.2	10 m 8.8	20 m 6.4	10 m 9.5	40 m 4.5	10 m 9.0	10 m 11.6
50 m 4.3	15 m 8.4	30 m 4.9	25 m 7.3		25 m 6.6	25 m 5.4
185 m 3.6		68 m 3.6	50 m 4.6		60 m 4.1	50 m 4.8
			150 m 3.8			
			Oxygen mg./l.			
Surf. 10.1	Surf. 9.3	Surf. 9.8	Surf. 11.5	Surf. 9.2		
185 m 7.1	10 m 10.1	68 m 11.1	10 m 10.3	40 m 10.6		
	15 m 10.5		150 m 10.4			
			pH			
Surf. 7.5	Surf. 8.0	Surf. 7.4	Surf. 8.1	Surf. 7.9		
185 m 7.3	10 m 7.7	68 m 7.5	10 m 8.0	40 m 7.7		
	15 m 7.7		150 m 7.6			
			Secchi disc. m.			
4.2	1.1	1.3	7.0	2.0		

CHRISTIE BAY

Temperature conditions in Christie bay were observed briefly in 1944 and 1945 and more extensively in 1946 and 1947. Table XIV presents data for the deep water station 36, in the centre of the bay, table XV for station 35, south of Pearson point and table XVI for various stations in the vicinity. It was indicated above, in discussing surface temperatures, that the summer season in Christie and McLeod bays is nearly a month later than that of the main lake. Thus in graph A, fig. 17, the curve shows very low temperatures on July 12 and complete circulation still present on July 16, 1947. However, the curve for July 5, 1946, indicates moderate warming in the upper 25 metres and this is probably normal since the break-up of ice in 1947 was unusually late. Warming progressed regularly in 1946 as shown by the curves for July 19 and August 19. Most of the heat

TABLE XIV. Limnological observations at station 36, Christie bay, 1946 and 1947.

	1946				1947			
	July 5	July 19	Aug. 4	Aug. 19	July 12	July 18	Aug. 14	Aug. 21
	Temperature ° C.							
Air	8.9	23.0	18.2	13.0	6.1	4.1	8.0	8.0
Surf.	9.2	16.5	14.8	12.1	2.2	3.5	6.6	6.2
2 m.	8.6	12.6	13.9	..	2.2	3.5	6.5	6.1
5	5.5	8.3	..	..	2.3	3.5	6.4	6.1
10	5.0	6.4	..	9.3	2.4	3.5	5.6	6.1
15	..	..	..	7.0	2.7	3.5	5.0	6.0
25	4.1	4.4	..	4.9	2.9	3.5	4.8	5.3
50	4.1	..	..	4.6	3.0	3.5	3.9	4.1
100	4.0	4.0	..	4.0	3.3	3.7	3.8	3.9
200	..	..	..	..	3.7	3.7	3.8	..
300	3.8	3.8	3.8	..	..	..	..	3.8
575	3.65	3.71	..	3.67	3.6	..	3.6	..
	Dissolved Oxygen mg./l.							
Surf.	11.4	11.1	11.4	10.0	12.4	12.3	12.1	12.2
10 m.	12.0	..	..	10.9	12.4	..	..	..
25	11.9	11.1	..	..	..	..	11.9	12.3
50	11.9	..	..	..	12.4	12.3	11.9	12.6
100	11.7	11.6	..	10.6	..	..	..	12.6
200	..	..	..	..	11.4	..	12.0	..
300	11.7	11.7	11.1	..	..	11.6	..	12.4
575	10.9	10.9	..	10.4	11.0	..	10.9	..
	pH							
Surf.	7.8	8.2	8.2	8.1	7.9	7.6	7.9	7.6
10 m.	7.7	..	..	7.9	7.7	..	..	..
25	..	7.5	..	..	..	..	7.8	7.6
50	..	..	..	..	7.7	7.6	7.7	7.5
100	..	7.5	..	7.7	..	..	..	7.5
200	..	..	..	..	7.6	..	7.6	..
300	7.7	7.5	7.5	..	..	7.6	..	7.5
575	7.5	7.5	..	7.6	7.5	..	7.6	..
	Secchi disc. m.							
	13.0	6.3	9.5	4.0	11.1	13.0	8.6	8.0

gained to August 1 was confined to the upper 15 metres. Late season records were not obtained at station 36 but the amount of heating can be inferred from records at station 35 which is only 6 miles south. The curve for August 29, 1946, at station 35 indicates extensive heating down to 50 metres. From comparison with events at station 31 it is inferred that cooling must have begun about

September 1 in Christie bay, thus the temperature series on August 29 approaches the time of maximum heating. Temperature series at station 36 for August 14 and 21, 1947, table XIV have not been plotted in fig. 19. They show that low temperatures continued throughout the summer.

Station 35 was established at a point one mile south of the harbour at Pearson point to compare this somewhat protected area with the open bay as represented by station 36. In fig. 17, graph B shows curves for station 35 for approximately the same dates as those in graph A. Comparing the mean temperatures of these two stations throughout the season it was found that the mean at station 35 was

TABLE XV. Limnological observations at station 35, south of Pearson point, 1946 and 1947.

	1946					1947			
	July 3	July 18	Aug. 1	Aug. 18	Aug. 29	July 11	July 17	Aug. 13	Aug. 21
	Temperature ° C.								
Air	12.0	22.0	13.8	21.1	14.0	8.8	10.1	10.7	9.6
Surf.	6.9	13.1	11.2	11.9	12.6	3.7	4.4	7.6	8.0
2 m.	..	10.1	..	..	..	3.5	3.7	7.6	7.9
5	..	8.6	10.4	..	..	3.5	3.7	7.5	7.8
10	6.0	6.0	7.5	10.9	12.6	3.4	3.7	6.8	7.8
15	..	..	6.6	8.1	12.6	3.4	3.6	6.4	7.7
25	4.8	4.3	..	6.1	9.5	3.4	3.6	5.8	6.2
35	..	..	4.5	..	8.2	3.5	3.6	5.3	5.8
50	4.1	4.1	4.2	4.5	5.3	3.5	3.7	4.6	5.7
100	4.0	4.0	..	4.2	..	3.6	3.7	4.1	5.2
140	3.9	4.05	3.95	4.0	4.3	3.6	3.7	4.0	4.9
	Dissolved Oxygen mg./l.								
Surf.	12.3	11.3	10.4	11.0	10.0	11.9	12.0	11.1	11.6
10 m.	12.7	11.4	..	..	10.0	12.1	..	..	..
15	..	..	11.2	10.9	..	..	..	..	..
25	11.7	11.2	..	..	10.7	12.1	..	11.6	11.8
50	11.4	11.3	10.9	..	..	12.1	..	11.7	11.9
140	12.0	11.3	11.2	10.7	10.4	12.1	11.7	11.6	11.9
	pH								
Surf.	8.3	8.0	8.0	8.1	8.0	7.7	7.7	7.9	7.8
10 m.	8.2	7.9	..	..	..	..	..	..	..
15	..	..	7.7	8.3	..	..	..	..	..
25	..	..	..	..	7.7	7.7	..	7.8	7.7
50	8.2	7.7	..	..	..	7.7	..	7.8	7.7
140	7.9	7.7	7.8	7.8	7.5	7.7	7.7	7.7	7.5
	Secchi disc. m.								
	5.0	6.7	7.5	4.5	7.0	10.0	8.1	7.6	6.3

TABLE XVI. Limnological observations at various stations in the vicinity of Christie bay.

Sta. 14 1 mi. W. of Snowdrift Aug. 24/44	Sta. 30 7 mi. N. of W. end of Redcliff Island Aug. 18/45	Sta. 42 Centre of Wildbread Bay Aug. 21/46	Sta. 46 N. Entrance of Pearson Harbour Aug. 15/47	Sta. 41 2 mi. from Outlet, Stark Lake Aug. 19/46	Sta. A 5 mi. from outlet, Artillery Lake Aug. 11/45
			Temperature ° C.		
Air 21.0	Air 14.5	Air 16.8	Air 10.1	Air ..	Air ..
Surf. 13.5	Surf. 12.0	Surf. 15.1	Surf. 10.4	Surf. 16.3	Surf. 8.4
28 m 9.1	10 m 6.3	10 m 13.0	1 m 9.3	10 m 16.3	26 m 6.6
	170 m 3.8	15 m 9.0	2 m 8.8	15 m 12.6	
	340 m 3.8	25 m 6.1	5 m 5.1	20 m 8.9	
		50 m 5.1	8 m 4.6	60 m 5.8	
		116 m 4.1	12 m 4.5		
			Oxygen mg./l.		
Surf. 10.9	Surf. 9.6	Surf. 9.3		Surf. 9.0	Surf. 10.6
28 m 11.1	170 m 10.6	10 m 10.1		60 m 10.7	26 m 10.9
	340 m 10.6	116 m 9.9			
			pH		
Surf. 7.7	Surf. 7.4	Surf. 7.8		Surf. 7.5	Surf. 7.0
28 m 7.4	170 m 7.4	10 m 7.7		60 m 7.4	
	340 m 7.4	116 m 7.5			
			Secchi disc m.		
4.5	7.0	7.4		4.5	13.0

warmer than that at 36 by an average of 0.2° C. This additional heating was mostly in the upper 25 metres, the temperatures at 50 and 100 metres being essentially the same at both stations.

Temperature series at various places around Christie bay are recorded in table XVI. Warming at the shallow water station 14, west of Snowdrift is contrasted with the extreme cold of shallow station 46, at the north side of Pearson point. Observations at station 30, August 18, 1945, are the only deep water records for Christie bay in that year. They indicate warming progress somewhat slower than that of 1946. Records for Stark and Artillery lakes suggest that smaller lakes in the region warm somewhat faster than Christie bay. Even Artillery lake which is 700 feet higher than Great Slave and which extends east into the barren lands, had warmed to 6.6° C. at 25 metres on August 11, 1945.

The mean temperatures and quantities of heat taken into Christie bay are of interest in comparison with those of the main lake. The mean temperature of Christie bay on August 19, 1946, corrected for the volumes of depth strata as given in table III, was 4.56° C. On August 29, 1946, using temperatures from station 35 for the upper 100 metres, the mean temperature was 5.11° C. This is to be compared with mean temperatures in the main lake, station 31, at the end of August 1946 and 1947 averaging 7.2° C. Because of the volume of deep water in Christie bay the mean temperatures are somewhat misleading. It is more instructive to compare the simple mean temperatures (not corrected for

volume) of the upper 100 metres. On this basis Christie bay had a mean of 7.4° C. on August 29 while the mean of the corresponding layer of the main lake at station 31 was about 6.9°.

The summer heat income of Christie bay in 1946 may be calculated in the usual way from data already presented. The mean temperature on August 29, 1946, correcting for the relative volumes of depth strata was 5.11° C. This represents a warming beyond the 4 degree point of 1.11° over a mean depth of

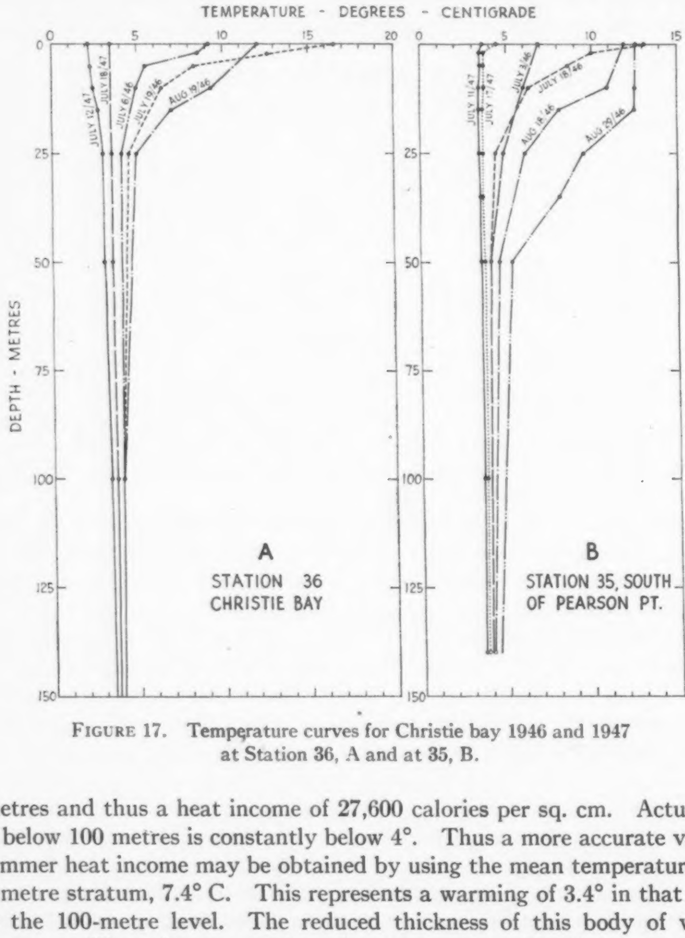

FIGURE 17. Temperature curves for Christie bay 1946 and 1947 at Station 36, A and at 35, B.

249 metres and thus a heat income of 27,600 calories per sq. cm. Actually the water below 100 metres is constantly below 4°. Thus a more accurate value for the summer heat income may be obtained by using the mean temperature of the 0-100 metre stratum, 7.4° C. This represents a warming of 3.4° in that volume above the 100-metre level. The reduced thickness of this body of water is 87.5 metres. Thus the summer heat income becomes 29,800 cal. per sq. cm. This is greater than that of the main lake by at least 50%.

Strøm (1944) suggests that in calculating heat gains in deep lakes the true temperature of maximum density should be used rather than the approximation

4.0° C. If this is done for Christie bay a summer heat income to August 29, 1946, of the order of 34,000 cal. per sq. cm. is obtained. It may be noted that Hutchinson (1941) and others consider the theoretical maximum to be about 40,000 cal. per sq. cm. Regardless of the method of expression which may be favoured, it is clear that Christie bay in spite of its apparent low temperatures and short summer season, took in a large amount of heat during the summer of 1946.

The temperatures in very deep water listed in table XIV are constantly below 4.0° C., commonly referred to as the temperature of maximum density. The true temperature of maximum density is about 3.94° at atmospheric pressure and it decreases with increasing pressure to 3.6° at 300 metres and 3.3° at 600 metres (Strøm, 1945). Thus our observations of 3.8° C. at 300 metres and 3.6° to 3.71° at 575 metres are well above the true temperatures of maximum density. There are, of course, numerous observations below the temperature of maximum density in the period between the break-up of the ice and the cessation of full circulation. These occur only between the surface and 200 metres. At 200 metres the temperature of 3.7° observed on July 17, 1947, is practically equal to the temperature of maximum density at that depth. Temperatures well below 4.0° have been recorded from many deep lakes in different parts of the world. In Crater lake, Oregon, Kemmerer *et al.* (1923) report a temperature of 3.5° C. at 500 and 600 metres. Werescagin (1936) records temperatures of 3.46° and 3.47° at 600 metres in lake Baikal and Strøm (1945) observed a temperature of 3.62° at 500 metres in lake Hornindalsvatn, Norway. The Great Slave lake readings are somewhat higher than those from corresponding levels of other very deep lakes. The reversing thermometers used in Christie bay were not recently calibrated and observations were corrected only for the temperature of the instrument at the time of reading. Thus no high precision could be expected and the readings to hundredths of degrees are of doubtful significance.

McLeod Bay

Four series of temperature observations in McLeod bay are recorded in table XVII. An additional bathythermograph record 10 miles from the west end of the bay on July 18, 1947, shows temperatures identical with those at station 45 on July 19. As in other parts of the lake, warming was late in 1947. Temperatures on July 19 were well below the point of maximum density. Apparently 1945 was also a cold season since very little warming had occurred by August 8. On that date the temperature of 3.6° C. at 280 metres is close to the temperature of maximum density (3.63°) at that level, indicating an absence of heating after vernal circulation. Observations on August 13, 1945, at station 29, about 8 miles from the east end of the bay, suggest that fairly rapid heating had occurred during the second week of August. The latest seasonal observation in McLeod bay was on August 15, 1944. On this date considerable warming had occurred down to 50 metres. The mean temperature was 4.73° C. representing a heat income up to that time of 8,750 calories per sq. cm. This may be contrasted to an income of about 14,000 calories in Christie bay at the corresponding date in

TABLE XVII. Limnological observations at stations in McLeod bay.

Station 13 Aug. 15/44		Station 28 Aug. 8/45		Station 29 Aug. 13/45		Station 45 July 19/47	
			Temperature ° C.				
Air	12.0	Air	11.8	......		Air	5.6
Surf.	11.2	Surf.	5.3	Surf.	8.9	Surf.	3.5
5 m.	7.0	......		......		5 m.	3.5
10 m.	6.1	......		10 m.	5.0	10 m.	3.4
25 m.	4.5	25 m.	4.2	35 m.	4.3	25 m.	3.3
50 m.	4.3	140 m.	3.9	70 m.	4.3	50 m.	3.3
185 m.	3.7	280 m.	3.6			150 m.	3.4
			O_2 mg./l.				
Surf.	10.4	Surf.	10.3	Surf.	10.9	Surf.	12.6
185 m.	10.6	140 m.	11.9	35 m.	11.9	......	
		280 m.	10.7	70 m.	11.9	150 m.	11.7
			pH				
Surf.	6.9	Surf.	6.8	Surf.	6.6	Surf.	6.7
185 m.	6.9	140 m.	6.8	35 m.	6.8	50 m.	6.7
......		280 m.	6.8	70 m.	7.0	150 m.	6.7
			Secchi disc. m.				
	10.7		16.0		11.1		15.6

1946 remembering of course, that 1945 is believed to have been a somewhat colder or later season than 1946. It is probable that McLeod bay stores less heat during the summer than Christie bay but observations after August 15 would be required to verify this.

SEASONAL CYCLE AND ICE COVER

Wide variation in the time at which thermal events are observed in different parts of the lake is illustrated by the records discussed above and in a striking way by the dates of formatión and disintegration of the ice cover.

The vernal circulation may begin with the break-up of the ice cover, that is about June 1 to 15 in the main lake and two weeks to a month later in McLeod and Christie bays. It is commonly observed, however, that a period of one to two weeks may elapse while the upper waters are warming toward the point of maximum density and that complete circulation does not occur until surface temperatures above 3° C. are reached. This was well illustrated at station 31 in 1947. The ice broke up about June 25. Temperature series on June 25 and July 6, table V, show that circulation was not complete but on July 9, fig. 13 B, mixing was complete to the bottom, 135 metres. Again at station 36 in Christie bay,

data for July 12, 1947, table XIV and fig. 16 A, show that the upper water had not yet warmed sufficiently to allow mixing. Observations at weekly intervals at station 31, with a few additional bathythermograph records, show that the duration of complete circulation in the main lake was at least 14 days in 1946, 7 in 1947 and 6 in 1948.

The progress of thermal stratification has been described above, pages 39 and 45. Beginning in the main lake about mid-July, the thermocline is frequently lowered to 15 metres in a two-week period but it may be temporarily disturbed at any time in August. Warming to 8° C. or more at 25 metres is usually observed by the middle of August and to 50 metres by the tenth of September. Loss of heat, as indicated by the trend of mean temperatures, usually begins about September 1. The latest series of observations, made on September 21, 1947, shows the upper 25 metres still at 7° C. while water at 50 metres and below was 4.5° and lower. Thus complete autumn circulation had not yet begun. From the rate of cooling observed between September 9 and 21 it would seem probable that complete circulation would occur before September 30. Thus there would be a mixing period of nearly three months before the main lake was again covered with ice.

The coming and going of the ice is of great importance in the life of isolated communities around the lake. Records covering periods of 10 to 15 years were provided for our use through the kindness of several detachments of the Royal Canadian Mounted Police and other residents of the area.

Ice begins to form in the small bays of Great Slave lake about October 15 and navigation usually ceases about October 10. The large bays begin to freeze about December 1 and the main lake is completely covered between December 15 and January 1. The 2½ months of ice forming is balanced by a similar period of breaking up in the spring. The Mackenzie river usually opens between May 15 and 24 and the Slave river slightly earlier. Small bays, as at Rae and Yellowknife open about May 25. The Resolution and Hay river areas usually have open water in the first week of June and Yellowknife bay is clear by this time but the central part of the lake is often covered with ice until June 15. In 1944 the main lake cleared early, about June 8, in 1945 about June 12, 1946 June 5, in 1947 June 23 and in 1948 June 16. Ice remains in the Hearne channel for a week or more after the main lake is open. The south part of Christie bay, near Snowdrift opens about June 20 and McLeod bay usually clears between June 24 and July 1. In summary, navigation lasts about 4 months, the freezing and breaking periods occupy 2½ months and the complete ice cover persists for about 5½ months.

The thickness of the ice varies in different localities and from year to year. It is reported to vary inversely with the thickness of the early winter snow cover. It is usually 2.5 to 3 feet thick by January 15 and reaches a maximum of between 5 and 6 feet about March 1. As the ice thickens great pressure ridges often 6 to 10 feet high and sometimes more than 30 miles in length, are formed. These are serious obstacles to the tractor trains which cross the lake.

LIGHT PENETRATION

Light penetration was measured with a standard Secchi disc 20 cm. in diameter. Observations were made at all limnology stations and are recorded in tables IV to XVII. Numerous additional readings were made along with surface temperatures and in special locations such as the very muddy water of the delta and the very clear water of McLeod bay.

Transparency readings with a Secchi disc provide a quick and reasonably accurate measure of light penetration in waters without excessive colour or turbidity. The writer has checked this relation using figures for lake Erie from Chandler 1942 and for uncoloured lakes in Wisconsin from Birge and Juday 1929. Plotting the logarithm of the Secchi disc readings against the depth to which 1% of the incident light penetrates, an approximately straight-line relation is obtained. The relation is expressed by the equation $\log S = .117\ m - .495$, where S is the Secchi disc reading in metres and m the number of metres to which 1% of the light penetrates. The following values for Secchi disc readings and equivalent depth of penetration of 1% of the light are useful as a rough guide to field observation.

Secchi disc 0.5 m	— 1% at 1.7 m.	Secchi 5 m	1% 10.3 m.
,, ,, 1.0 ,,	— ,, ,, 4.3 ,,	,, 10 ,,	,, 12.9 ,,
,, ,, 2.0 ,,	— ,, ,, 6.8 ,,	,, 14 ,,	,, 14.0 ,,

There is some indication that this relation does not hold for extremely clear lakes such as Crystal lake, Wisconsin where the Secchi disc is seen to about 11 metres but 1% of the incident light penetrates to nearly 18 metres.

The Main Lake

Light penetration in the main lake is usually indicated by a Secchi disc reading of less than five metres while in the east arm readings are almost always greater than five metres. It is therefore desirable to consider first, conditions found in various parts of the main lake.

Seasonal trends in light penetration at station 31, off Gros Cap, are shown in the graph, fig. 18. In 1946 and 1947 disc readings were from 5 to 7.4 metres in late June, between 7 and 8 in mid-July and then dropped to below 4 in early August. A second increase after the middle of August was followed by a decline in September. In 1948 the situation differed greatly from that observed in the preceding years. Transparency dropped by mid-July to about 1 metre and remained low through July and most of August. The midsummer readings for station 31 in 1948 are between 0.5 and 2.0 metres. This is far below the average for offshore areas in the open lake. Since this condition accompanies the observation of unusually high surface temperatures at station 31 it might be related either to increased plankton growth or to warm turbid surface water blown in from the south, or to both of these factors.

The usual range of transparency in offshore waters in the western part of the main lake is indicated in fig. 19. With one exception they lie between 2 and

4.5 metres. The exception is the observation of 5.7 metres made on August 7, 1944, at station 11, in the centre of the west arm. If these values are averaged a trend is observed from about 2.5 at June 25 to 4.0 on July 25 and back to 2.5 at the end of August. The average of all readings in the offshore area of the open lake is 3.6 m., which according to the analyses quoted above, indicates penetration of 1% of the incident light to about nine metres.

Observations from the Slave delta and other inshore areas around the main lake are also plotted in fig. 19. The transparency in these areas rarely exceeds 2.2 metres and may go as low as 0.07 metres. The mixing of water entering the lake from the Slave river is indicated by the gradual increase in Secchi disc

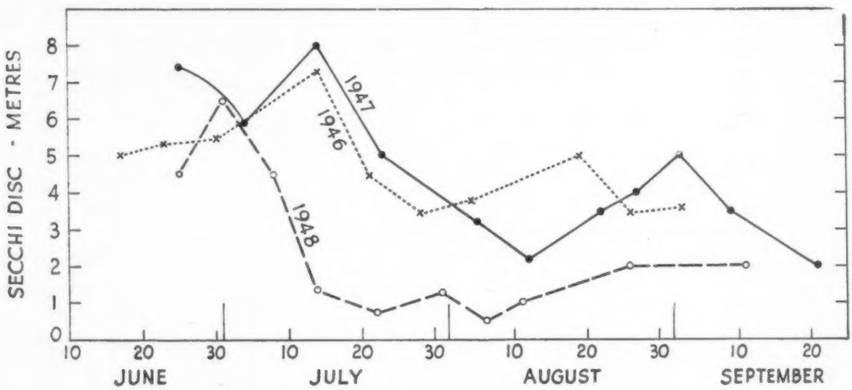

FIGURE 18. Secchi disc readings in the main lake at Station 31 for the years 1946, 1947 and 1948.

readings northward from the mouth of the river. Readings of 0.05 to 0.1 metres have been recorded just inside the river mouth. The following are the ranges of Secchi disc readings at various mileages north from the delta.

1 mile — 0.05 to 1.0 m.	10 miles — 0.25 to 1.5 m.
2 ,, — 0.2 to 0.35 ,,	15 ,, — 0.5 to 2.1 ,,
5 ,, — 0.1 to 0.75 ,,	25 ,, — 0.8 to 3.0 ,,

The Outpost islands are located 25 miles north from the delta and visibly muddy water often extends north and east beyond this group. Observations at the mouths of other rivers flowing into the lake have shown heavy loads of silt comparable to that of the Slave river. At the mouth of Big Buffalo river a Secchi disc reading of 0.12 was made in June 1946. At Frank channel near Rae, one of 0.07 on July 6, 1947. The Taltson river with its rocky drainage basin, carries little silt. On July 12, 1946, a Secchi disc was visible in the river to a depth of 2.2 metres. The Lockhart river was not measured but observations from the air showed it to be quite clear.

The East Arm

The high transparency of the east arm is evident from data plotted in fig. 19. Readings in Christie bay range from 4.0 to 13.0 metres and the average is 7.6 which is more than double that of the open water of the main lake. The equivalent level to which 1% of the incident light penetrates is about 12 metres. Observations in mid-July are about three metres deeper than those in mid-August. This is believed to be related to the greater development of plankton in August.

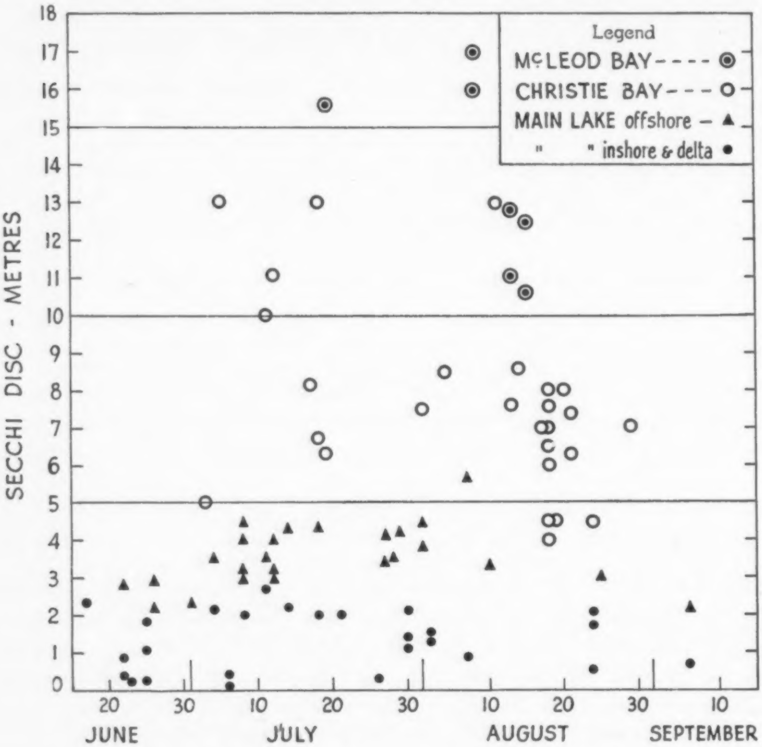

Figure 19. Secchi disc readings in various parts of Great Slave lake, 1944 to 1947.

The transparency of McLeod bay is greater again than that of Christie. Seven observations for McLeod bay in fig. 19, range from 10.6 to 17.0 and average 13.7 metres. This would suggest penetration of 1% of incident light to about 14 metres, but as has been indicated, extremely clear lakes may not follow closely the formula derived above.

The general relation of lowest disc readings near shore and highest near the centre of the lake is illustrated in fig. 20, by observations taken from one end of

McLeod bay to the other on August 7 and 8, 1945. The transparency at Taltheilei narrows, where the bay empties into the remainder of the lake, was 7.2 metres. A fairly regular increase in the readings was observed from this to a maximum of 17.0 metres at a point 54 miles east. This was followed by a decline through the remaining 29 miles to a reading of 9.7 metres at Reliance, the east end of the bay. Comparing the disc readings in fig. 20 with the depths shown in fig. 5, it will be seen that the greatest transparency occurred near the centre of the deep water and that the decrease in transparency was more pronounced in the somewhat shallower west half of the bay.

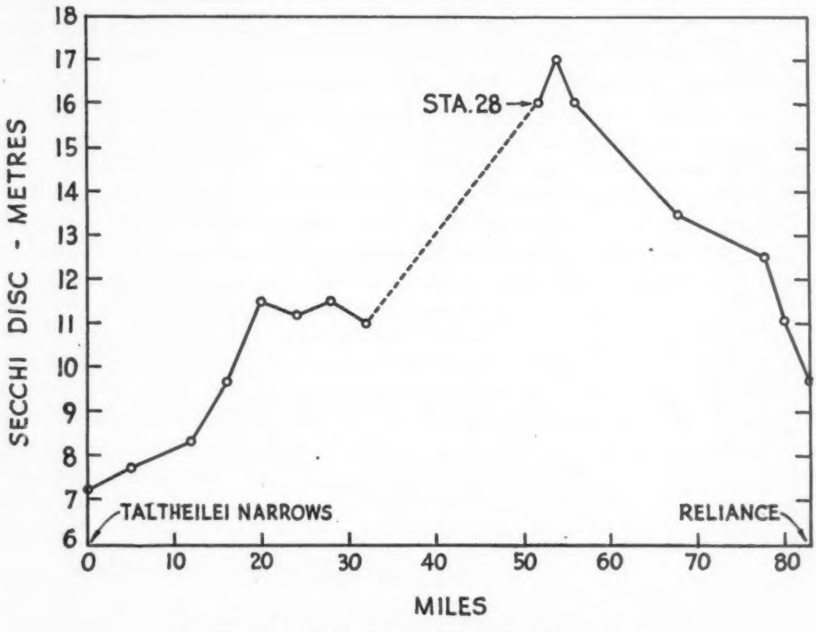

FIGURE 20. Secchi disc readings from end to end of McLeod bay August 7 and 8, 1945.

Transparencies even greater than those of McLeod bay have been reported by Miller (1947) for Great Bear lake. He observed a secchi disc at 29 metres in the open lake, at 20 metres near shore and 7.5 metres in enclosed bays. The maximum transparency observed in lake Athabaska was 7.5 metres (Rawson, 1947).

DISSOLVED OXYGEN

Determination of dissolved oxygen was made on samples from each of the stations listed in tables IV to XVII. Samples were taken at the surface, near bottom and from one or more intermediate points depending on the depth of the station, the temperature gradient and the time available. Analyses were made

promptly using the Miller method (De Laporte 1920). Saturation standards are those recommended by Ricker (1934) and they have been corrected for the altitude of Great Slave lake, 162 metres.

Seasonal Cycle and Saturation

The most extensive record of dissolved oxygen in Great Slave lake is that for station 31, off Gros Cap for the years 1946, 1947 and 1948, tables IV, V and VI. Surface oxygen at this station varied from 9.0 to 13.0 mg. per l. and near bottom

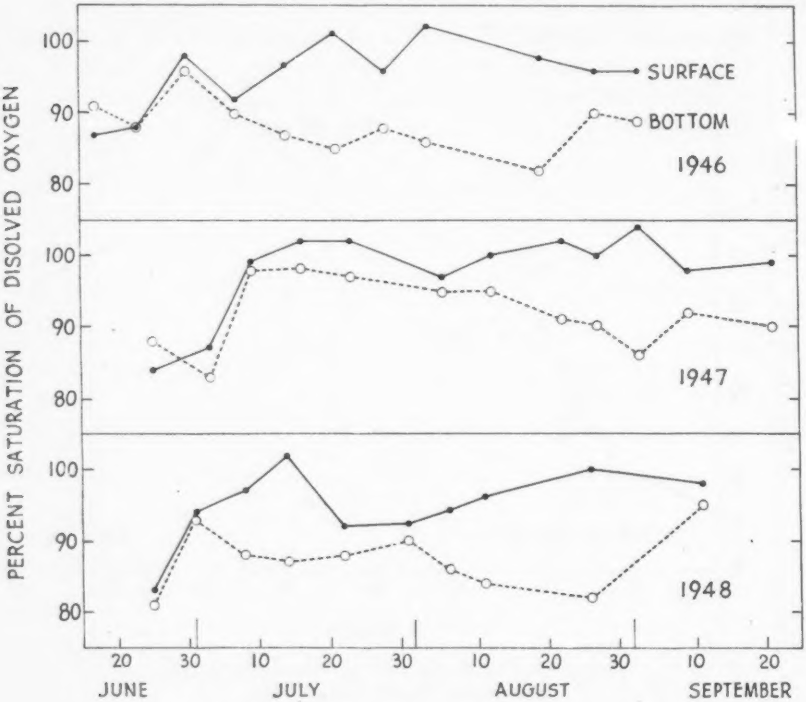

Figure 21. Oxygen saturation of surface and bottom water at Station 31, 1946 and 1947 and 1948.

oxygen from 10.4 to 13.0. Per cent saturations have been calculated for surface and bottom determinations and are plotted in fig. 21. In the three years of observation supersaturation occurred at the surface seven times. The highest was 104% on September 2, 1947. These instances are thought to have resulted from rapid warming of the surface water. Four instances of supersaturation at depths of 7 to 12 metres are also recorded. These are at station 5, Yellowknife bay on July 29, 1947, and at stations 7, 17 and 43 in table XI. The excess oxygen in these cases was presumably the result of algal photosynthesis. The minimum

saturation value near bottom (140 metres at station 31) was 82%, observed August 19, 1946, and on August 26, 1948. This high degree of saturation in deep water is a clear demonstration of the oligotrophic conditions in the lake.

In 1946 the per cent saturations at surface and bottom were equal at 88% on June 23 and differed by only 2% until July 7 (fig. 21). Then, as the surface waters warmed and thermal stratification developed, the bottom oxygen began to decrease. The minimum of 82% was reached on August 19. A disturbance between July 21 and 28 caused some change in the deep temperatures (table IV) but the oxygen saturation values were only slightly altered. There was little change in the surface and bottom saturation values between August 27 and September 2 but examination of the amounts at intermediate depths, table IV, show that mixing had been extensive to at least as deep as 50 metres.

The cycle of oxygen saturation during 1947, as indicated in fig. 21, shows consistently high saturation values at surface and bottom throughout the summer. This may be related to the low mean temperatures and less stable stratification which prevailed in 1947 as compared to 1946 and 1948. Deep water oxygen in 1947 was never lower than 86% saturation. The spring period of complete circulation, described in connection with the temperature curves graph B, fig. 13, is also well illustrated by the changes in oxygen content. Between July 3 and 9 complete mixing took place, raising the amount of oxygen from about 11 to 13 mg. per l. and causing a sharp rise in the saturation values.

In 1948 the oxygen content of the surface water rose from a low point on June 25 to a high value on July 14, then dropped in late July and rose again during August. The deep water oxygen began to decrease after July 1 but was partially replenished between July 22 and 31 in a disturbance similar to that observed on July 28, 1946. It decreased again during August to a low of 82% saturation on August 26. Relatively high temperatures in the epilimnion and somewhat stable stratification made the oxygen conditions in 1948 resemble those of 1946 rather than 1947 in which the epilimnion was cool and stratification frequently disturbed.

Amounts of Oxygen and Oxygen Deficits

The ratio of the amount of oxygen in the hypolimnion to that in the epilimnion at midsummer has been used as an expression of oligotrophic or eutrophic character of lakes. By assuming a uniform slope from the shoreline to the 25 metre contour in Great Slave lake the approximate volume of the epilimnion (0-10 metres) has been calculated to be 24% of the volume of the main lake. On August 19, 1946, the mean oxygen content of the epilimnion was 10.0 mg. per l. and that of the hypolimnion 10.25 mg. Thus the ratio O_2H/O_2E on this date was 3.25. Similar calculations for August 11, 1948, give a value of 3.4. These values are well up in the oligotrophic range but Christie Bay is far beyond them. The 0-10 metre stratum of Christie bay makes up only 4% of its total volume. On August 19, 1946, the mean oxygen content of the epilimnion was 10.4 mg. per l. and that of the hypolimnion 10.7. Thus the ratio of O_2H/O_2E was 24.2. Seneca, the deepest of the Finger lakes of New York, quoted by the writer (Rawson 1935) as an example of extreme oligotrophy, has an O_2H/O_2E ratio of 10.4.

Hypolimnial oxygen deficits have been used with some satisfaction in smaller lakes as indicators of organic production. The rather unstable thermal stratification and the suggestion of massive water movements make the calculation of deficits in Great Slave lake somewhat unsatisfactory. However, the oxygen data from station 31 for the years 1946 to 1948 should be examined in this connection.

In 1946, complete circulation continued until June 30 when the maximum amount of oxygen, 12.5 to 12.6 mg. per l. was observed at all depths except surface and saturation ranged from 96 to 98%. The amount of oxygen in the hypolimnion as shown in table IV, appears to have dropped rather sharply from June 30 to July 7 and then gradually to a minimum at August 19. The rapid decrease during the first week is difficult to interpret. Between August 19 and 27 the stratification was disturbed as shown by the temperature curves and by increased oxygen values in the hypolimnion. Since the hypolimnion was disturbed during the summers of 1947 and 1948 the oxygen values for August 19, 1946, would seem to be the most hopeful for calculation of hypolimnion deficits. The so-called "actual" deficit (from saturation at existing temperatures) of the hypolimnion on this date corrected for volumes of the depth strata, was 1.60 mg. per l. or 4.94 mg. per sq. cm. The "absolute" deficit (from saturation at 4° C.) was 2.63 mg. per l. or 8.15 mg. per sq. cm. Since it is known that the oxygen content at the close of circulation June 30, was 12.55 mg. per l. it would seem desirable to calculate the "exact" deficit as defined by Ricker (1934). Since the mean oxygen content of the hypolimnion on August 19 was 10.25 mg. per l. the exact deficit was 2.3 mg. per l. or 7.13 mg. per sq. cm. Knowing that these deficits developed in 50 days the average per day or per month may be calculated.

In 1947, after an unusually late break-up, thermal stratification was just beginning on July 23. At this time the hypolimnion was practically saturated (97.5%) with oxygen. A slight deficit had developed by August 5 but on August 12 thermal stratification and oxygen content was disturbed, presumably by a mass of cold water moving in at station 31. A further decrease in oxygen developed until September 2 and by September 9 mixing and a considerable restoration of hypolimnial oxygen had taken place. The course of oxygen change at station 31 throughout the season of 1947 was sufficiently erratic that the data are not considered suitable for the calculation of deficits.

In 1948, on July 1, the hypolimnion was well mixed and had a mean oxygen content of 12.25 mg. per l. and saturation of 95%. Theoretically it could have increased to 12.85 mg. per l. (saturation at 4° C.) between July 1 and 8 when the next observations were made. A slight decrease in hypolimnial oxygen had occurred by July 8 and a pronounced drop between July 8 and 14. Data for July 31 show that a major disturbance had taken place in the oxygen content as well as in the temperature relations. Hypolimnial saturation had increased from 85% on July 22 to 90% on July 31. By August 6 the hypolimnial oxygen was back at about the same level as on July 22. It continued to decrease until August 11 but by August 26 it had been restored to nearly saturation (96%) at depths down to 50 metres. The bottom sample (140 metres) on August 26 still

showed a deficit, 82% saturation. By September 11 complete mixing had occurred. Because of the disturbance of stratification which occurred between July 22 and 31 it might be well to refrain from calculating deficits for 1948 as well as for 1947. It is possible, however, that the July 31 observations indicate only a temporary displacement of the upper water at station 31 by colder water from the Hearne channel. The rapid re-establishing of the oxygen deficit by August 6 would support this view. If this is accepted, the "absolute" deficit from about July 3 would be 12.85 mg. per l. (saturation at 4° C.) less 9.85 mg. per l. (the mean hypolimnial oxygen on August 11) or 3.0 mg. per l. This deficit developed in about 40 days (0.075 per day) as compared to the absolute deficit of 2.63 on August 19, 1946, which developed in 50 days (0.053 per day).

Oxygen in Christie and McLeod Bays

Oxygen data for Christie bay are recorded for station 36 in table XIV and for station 35 in table XV. As in the main lake, the progress of stratification was fairly regular in 1946 and less so in 1947. Saturation values were never below 81% even in the deepest water. This was not surprising since saturation of 70% had been recorded at a much greater depth, 1600 metres, in Lake Baikal by Werescagin (1936). Observations at station 36, July 5, 1946, show that circulation had ceased. Oxygen saturation reached 90% at 300 metres but only 83% at 575 metres. This suggests that replacement had not occurred in the greatest depths. Perhaps the viscosity of the water prevented circulation even though a homothermal condition had been established. The mean hypolimnial oxygen decreased to 10.7 mg. per l. on August 19. This represents an absolute deficit of 2.14 mg. Temperature and oxygen data for July 3 at station 35 and July 5 at station 36, suggest that complete circulation had ceased recently, probably about July 1. Thus the deficit had developed in about 50 days. In the same length of time at station 31 in the main lake the absolute deficit was 2.63 mg. per l. The latest observation in 1946 was at station 35, on August 29, table XV. The mean oxygen content of the hypolimnion was 10.6 mg. per l. representing an absolute deficit of 2.28 mg. per litre.

In 1947 the oxygen conditions in Christie bay were marked by high saturation and frequent renewal similar to that observed for the same year in the main lake. Thus no deficits have been calculated. The effect of these disturbances was more marked at the shallower station 35, than at the deep water station 36. At station 35 the lowest oxygen saturation value in 1947 was 90%, contrasted to 82% in 1946.

Oxygen determinations in McLeod bay, table XVII reveal conditions much like those in Christie bay at corresponding dates. The minimum observed saturation value near bottom was 81% in 1944 and 82% in 1945. The data are considered too meagre to justify calculation of deficits.

The significance of hypolimnial oxygen deficits in Great Slave lake as an indication of biological productivity cannot be assessed without further information as to the chemistry of the deep water and some knowledge of the quantity of plankton present. There is some doubt as to whether the observed deficits

in deep water of Christie bay are mainly biological in origin, that is, resulting from the oxidation of falling bodies of plankton organisms. The recorded deficits seem rather high in relation to the preliminary observations of plankton and fish production. To make only one comparison, Cultus lake, British Columbia, studied intensively by Ricker (1937) developed an absolute hypolimnial oxygen deficit of about 0.6 mg. per l. per month in the years 1932 to 1934. The absolute deficit at station 31 in the main part of Slave lake in 1946 was about 1.6 mg. per l. per month. It is doubtful whether the open water of Great Slave lake has as great productivity as the smaller and warmer Cultus lake.

HYDROGEN ION CONCENTRATION

The determination of pH or hydrogen ion concentration was made colorimetrically using phenol red, cresol red and bromthymol blue indicators and La Motte colour standards. The results of analysis at each station are recorded in tables IV to XVII. Some analysis of these data is presented in table XVIII which shows the range of pH observed in surface and bottom waters in various parts of the lake.

TABLE XVIII. The range of hydrogen ion concentration observed at stations in various parts of Great Slave lake.

	Range of pH	
	Surface water	Bottom water
Main Lake (West of 113°)		
Station 31, off Gros Cap	7.7 - 8.3	7.3 - 7.8
Offshore—West Arm	7.5 - 7.8	7.1 - 7.9
Offshore—North Arm	7.6 - 7.9	7.4 - 7.9
Yellowknife Bay	7.7 - 8.0	7.4 - 7.7
Inshore Main Lake	7.6 - 8.0	7.5 - 8.0
Off Slave Delta	7.7 - 8.0	7.7 - 8.0
East Arm		
Islands section	7.5 - 8.1	7.3 - 7.7
Christie bay, Station 35	7.7 - 8.3	7.5 - 7.9
" " " 36	7.6 - 8.2	7.5 - 7.7
Christie bay, vicinity	7.4 - 7.8	7.4 - 7.5
McLeod bay	6.6 - 6.9	6.8 - 7.0

The surface water of the main lake varies from pH 7.5 to 8.3 and is usually near 8.0. The pH of offshore waters tends to be slightly lower than inshore but the muddy inflow of the Slave river does not differ from the clear water of Christie bay. The pH of bottom water from any considerable depth averages about 0.3 lower than surface at the same place. No regular seasonal trends were detected in the change of surface pH. The pH of bottom water at station 31 was

low in June 1947 before circulation occurred, table V, and it tended to decrease slightly from the onset of stratification until the autumn turnover, table IV.

In the islands area and in Christie bay the range of pH in surface and bottom waters differed little from that in the main lake. Water at station 35 near Snowdrift, was slightly but consistently more alkaline than that at the deep water station 36, of Christie bay. In the greatest depths at station 36, table XIV, the pH of water from 575 metres was 7.5 or 7.6 and that at 300 metres 7.5 to 7.7. McLeod bay differs from the remainder of the lake by being slightly acid. The pH of its surface water was 6.6 to 6.9 and at bottom from 6.8 to 7.0.

Lake Athabaska has a pH of 6.6 at its east end where it receives drainage only from precambrian areas and 7.7 at the west where the Athabaska river enters. In this respect it resembles Great Slave with its most acid water, McLeod bay, at the eastern extremity. Miller (1947) reports that the pH of Great Bear lake was constantly between 7.2 and 7.4. The typical pH range of 7.7 to 8.3 in Great Slave lake is similar to that of lake Winnipeg, lake Nipigon and lake Superior.

MINERAL ANALYSES

Water from various parts of Great Slave lake has been analysed for total solids and the main mineral constituents. Samples were taken to the University of Saskatchewan where the analyses were made from two to five months after collection. Large quantities of suspended materials were present in some samples and these were removed by prolonged settling and decantation. The suspended silt from a few samples was measured by drying and weighing. A sample from four miles off the Slave river delta, June 10, 1946, contained 116 mg. per l. of suspended material of which 19 mg. was organic. The Secchi disc reading in this water was 0.2 metres.

The total solids in water from different parts of the lake appear to vary with inflow from adjacent rivers. Thus areas receiving drainage from bare precambrian rocks are low in minerals in contrast to the areas receiving water from the Slave river and other rivers from the lowlands area.

The total solids in water from the main lake average about 150 p.p.m., table XIX. Samples from widely separated points, Hay river and Jones point, had 148 and 147 p.p.m. Station 33, 12 miles north of the delta had 160 showing the effect of proximity to the Slave river inflow. Another sample taken 4 miles north from the delta on June 10, 1946, had 174 p.p.m. A bottom sample near Outpost island had 140 p.p.m. presumably because of slight dilution by water from the east arm. A Yellowknife bay sample with only 60 p.p.m. was apparently diluted by drainage off the precambrian rocks.

In the east arm, Christie bay had 111 p.p.m. at its central station and 107 off Snowdrift which is near the point of inflow of the Snowdrift river, table XIX. A sample taken from McLeod bay in 1945 had the extremely low total solids of 22 p.p.m. Because of the great interest in this low mineral content a second sample was obtained in 1949. In this the total solids were 23 p.p.m., calcium 3.1 and magnesium 1.8 p.p.m.

TABLE XIX. Mineral analyses of water from Great Slave lake. Total soluble solids expressed in parts per million.

Locality and date of sample	Total solids at 180° C.	Bicarbonates as HCO_3	Calcium as Ca^{++}	Magnesium as Mg^{++}	Sodium as Na^{+}	Sulphates as $SO_4^{=}$	Chlorides as CL^{-}
Main Lake							
Sta. 33 off Slave delta June 22/46	160	111.5	3.1	7.0	12.9	25	12.0
2 mi. off Hay River, Aug./47	148	99.0	24.8	..	..	..	..
2 mi. off Jones Point, Aug./47	147	100.1	26.1	..	..	..	..
Outpost Island, Aug., 1945	140	120.0	28.8	6.5	..	..	..
Sta. 7, Yellowknife Bay, Sept. 11/44	60	41.8	10.8	..	..	..	..
East Arm							
Sta. 36, Christie Bay, July 5/46	111	82.5	25.0	5.7	3.0	16	6.0
Off Snowdrift, Aug. 24/44	107	77.6	21.6	..	..	..	..
Sta. 28, McLeod Bay, Aug. 8/45	22	..	..	..	..	..	..
E. end McLeod Bay, Aug. 10/49	23	18.4	3.1	1.8	..	nil	nil

The great difference between the amount of minerals in McLeod and Christie bays is attributed to the extensive connection of the latter with the main lake whereas McLeod bay has only its narrow outlet at Taltheilei narrows. This effect of unmixed precambrian drainage in McLeod bay may be compared with the mixed condition in Yellowknife bay where 60 p.p.m. of total solids was observed.

In considering the low total solids of the east arm it should be noted that this part of the basin was filled with ice long after the origin of the main lake. But Christie bay is parallel to and therefore just as young as McLeod bay. Also the Snowdrift and Taltson rivers which enter the east arm drain precambrian areas like the Lockhart river which enters McLeod bay. It would seem therefore that Christie bay has two-thirds the solids of the main lake and McLeod bay

only one-seventh because of the more complete isolation of the latter from the main lake. We have no information as to the length of time this isolation has existed. Taltheilei narrows is only 500 yards in width but at slightly higher levels McLeod and Christie bays were connected through Lost channel and Wildbread bay (fig. 7). Assuming that the total solids in the Lockhart river are no greater than those in McLeod bay (22 p.p.m.) a considerable degree of dilution would result in what is a short time from the geological viewpoint. The Lockhart river has a mean annual discharge of about 3,300 cu. ft. per sec. This inflow alone would equal the present volume of McLeod bay in 640 years and there are of course other rivers entering the bay along its north shore.

The water of Great Slave lake is fairly soft, with an alkalinity or total hardness expressed as $CaCO_3$ of 70 to 95 p.p.m. The data in table XIX indicate that there is no shortage of calcium which in seven samples ranged from 10.8 to 31.0 p.p.m. and made up from 17 to 23% of the total solids. Magnesium, sulphates and chlorides were present in similar proportions in the water from the main lake and from Christie bay. Sodium appears to be more abundant in the main lake but this element was determined by difference and its measurement is therefore less reliable than those of the other minerals. Silica, not recorded in table XIX, was present in about four parts per million.

The possibility of variation in mineral content with depth was tested by two series of samples. On June 22, 1946, samples at station 33, twelve miles north of the Slave delta had at surface 164 p.p.m. total solids, at 50 metres 154 p.p.m. and at 90 metres near bottom, 167 p.p.m. On July 5, 1946, samples at station 36 in Christie bay showed remarkable uniformity of mineral content with determinations of 111 p.p.m. at surface, 300 metres and 575 metres.

The determination of 22 p.p.m. total solids in McLeod bay appears to be the lowest reported from any large lake. Clarke (1924) records two small lakes in Maine, Bass lake in Wisconsin and Crystal lake in California with total solids between 16 and 20 p.p.m. Among larger lakes, Cree lake, Saskatchewan, has 32 p.p.m., Karluk in Alaska (Juday *et al.* 1932) had 30 to 34 and lake Chelan, Washington, 44 p.p.m. (Kemmerer *et al.* 1923). On the other hand the water of the main part of Great Slave lake with 140 to 160 p.p.m. is a fairly "mature" water. It has more minerals than even the lower members of the Great Lake series which is Superior 60, Huron 108, Erie 133 and Ontario 138 p.p.m. to quote the mean values given by Clarke (1924).

Large lakes which lie entirely on the Canadian Shield are Reindeer which has 60 p.p.m. total solids, Nipissing with 51 to 56 (Leverin 1947), Lake of the Woods with 83 to 100 (Leverin 1947) and Nipigon 114 (Mackay 1949). It is recognized of course, that among lakes on the Canadian Shield the mineral load of the run-off will vary greatly according to the amount of soil cover in the drainage area. Much of the Shield in the vicinity of McLeod bay is of bare precambrian rocks, which no doubt accounts for the extremely low mineral content of the water of the bay.

Great Bear lake has 98 p.p.m. total solids and lake Athabaska had 52 p.p.m. total solids in a sample from Fond-du-lac at the east end, 58 p.p.m. at Goldfields

near the centre and 100 to 130 at the west end where the Athabaska river enters the lake. This gradation from lower mineral content in the east to higher in the west parallels that described above for Great Slave lake.

TYPOLOGY

Great Slave lake exhibits an oligotrophic condition which is more marked in the east arm and extreme in McLeod bay. This oligotrophy is determined primarily by morphometric and historical situations. The lake is large, very deep and geologically youthful. Climatic and edaphic influences also contribute to the oligotrophy but in special ways. The mean annual air temperature of 23° F. would suggest a sub-arctic climate but critical examination reveals a warm intense summer with long hours of sunlight. Thus the summer climate is not unlike that of lakes much farther south and east. Climate, therefore, is not regarded as a main factor in the oligotrophy of Great Slave lake. Again, the lake lies on the margin of precambrian formations which would appear to be unfavourable for the accumulation of nutrients and would thus promote oligotrophy. This is certainly true in McLeod bay but in the main lake the tremendous inflow of mineral laden water from the Slave river has an important moderating effect on the oligotrophy of the lake.

Evidence of oligotrophy in the main lake has been presented above under several headings. The vast and cold hypolimnion with oxygen saturation constantly above 80% may be cited, also the high value of 3.4 for O_2H/O_2E. Biological evidence from the study of plankton, bottom fauna and fish is also available. In a previous publication (Rawson 1947) it was pointed out that the average quantity of plankton in Great Slave lake was little greater than that of four large alpine lakes of the Canadian Rockies (Rawson 1942). A preliminary analysis of the bottom fauna showed an average of about 4 kg. dry weight per hectare, which is clear evidence of oligotrophy. The invertebrate population, the species of fish and apparently the capacity for fish production (Rawson 1949) resemble in many ways those of lake Superior and other large oligotrophic lakes of Canada.

McLeod bay may be described as approaching the ultimate in oligotrophic conditions. Its cold hypolimnion is about 15 times the volume of its epilimnion. Its transparency is high, its plankton and bottom fauna are scanty and its mineral content of 22 p.p.m. approaches the lowest reported for any lake water. In many respects McLeod bay resembles the open water conditions described by Miller (1947) for Great Bear lake. Such extremes of oligotrophy have heretofore been known chiefly from alpine lakes of small or moderate size. Further study of Great Bear and Lake Superior would be of special interest in this field.

The Slave river is seen as the great moderating factor in the trophic condition of Great Slave lake. In post-glacial times it brought down materials which filled in the original "south arm" of the lake, fig. 3. It continues to pour dissolved mineral materials into the lake at the rate of about 60,000 tons per day plus an additional 40,000 tons of suspended silt per day during the summer months.

Great Bear lake, with its drainage restricted to a rather small precambrian area had no such saving feature. It is also subject to more severe climatic conditions. Great Bear is thus much more oligotrophic than the main part of Great Slave lake. Great Bear was judged by Miller (1947) to be incapable of supporting a commercial fishery whereas Great Slave lake is now producing more than three million pounds of fish per year.

The study of regional limnology in the Mackenzie drainage area is merely begun in this and other recent studies such as those of Great Bear lake (Miller 1947) and lake Athabaska (Rawson 1947). Further studies of these three lakes together with lake Winnipeg should provide most interesting and valuable materials for comparison with the Great lakes. Another series of interest includes Cree and Reindeer which like Lake Nipigon, lie entirely on the Canadian Shield. A glance at the map of Christie and McLeod bays, fig. 7, will indicate the profusion of small lakes in the area, which are entirely unknown from a limnological standpoint.

SUMMARY

1. Great Slave lake, in northwestern Canada, lies across the boundary between the Mackenzie lowlands and the Canadian Shield. It is of recent origin and had four arms when the last ice sheet retreated. The south arm has been filled in by sediments brought down by the Slave river. About five-sixths of the inflow to the lake comes from the Slave river.

2. The climate of the Great Slave area is marked by long cold winters and a short but vigorous growing season with long hours of sunlight. Precipitation is low.

3. The lake is about 100 by 275 miles and its area is 10,500 square miles (27,200 sq. km.). The mean depth of the main lake is 41 metres and its maximum 163 metres (535 feet). The long east arm is very deep, a maximum in McLeod bay of 280 metres (920 feet) and in Christie bay 614 metres (2,015 feet).

4. Surface temperatures at midsummer average about 14° C. offshore and 16° inshore. Pronounced inshore to offshore gradients are often observed.

5. Thermal stratification is usually observed in the main lake from mid-July to late August but it is sometimes disturbed by water movements. The thermocline is commonly found between 10 and 18 metres in mid-August. Warming is mostly confined to the upper 25 metres but by early September warm water may be forced down to 50 metres. Summer heating in Christie bay is similar to that in the main lake but it begins about a month later and the season is shortened accordingly.

6. Deep water temperatures are fairly constant. At 100 metres the summer temperature is usually 4 to 4.8° C. although temperatures as low as 2.1° have been observed during the vernal circulation. At 300 metres the temperature range was 3.7 to 3.8° and at 575 metres 3.6 to 3.7°. Mean temperatures in the main lake usually reach 6.5° C. by the end of July and a maximum of 7.6° at the end of August.

7. Measurement of the amount of heat taken into the lake is made difficult by variation from year to year and by extra heating in the shallow areas. The summer heat income of the main lake is probably between 15,000 and 19,000 cal. per sq. cm. In Christie bay it may be from 28,000 to 30,000 cal. per sq. cm.

8. The thermal cycle in the main lake includes vernal circulation, usually about July 1; thermal stratification from about July 15 to the last week in August; partial circulation about September 1 and complete circulation probably from October 1 to freeze-up in late December.

9. Ice covers the lake completely for about $5\frac{1}{2}$ months. Freezing and breaking-up occupy about $2\frac{1}{2}$ months with great variation in different parts of the lake The main lake is usually free of ice by June 15.

10. Transparency of the main lake is indicated by Secchi disc readings of 4 metres, equal to penetration of 1% of incident light to 9 or 10 metres. Transparency varies widely, from a usual range of 0.1 to 1.0 metres near the Slave delta to 4 to 13 metres in Christie bay and 10 to 17 metres in McLeod bay.

11. Dissolved oxygen is usually present in the surface waters in amounts equal to 95 to 100% saturation and occasional supersaturation. Some decrease in the oxygen of the hypolimnion was noted during the summer but in no case did the saturation value at any depth fall below 82%. Hypolimnial oxygen deficits have been calculated and appear to be high in relation to other evidence of organic production.

12. Hydrogen ion concentration in the main lake is usually between pH 7.7 and 8.3 at the surface and about 0.3 lower at depths of 100 metres or more. McLeod bay has slightly acid water, pH 6.6 to 6.9.

13. Dissolved minerals in the main lake average about 150 p.p.m. Calcium and bicarbonates predominate. In the east arm, Christie bay had 111 p.p.m. and McLeod bay only 22. Variations in the total solids in different parts of the lake show the effect of dilute run-off from bare precambrian rocks as contrasted with the rich mineral supply brought in by the Slave river at the rate of 60,000 tons per day.

14. Great Slave lake is oligotrophic chiefly because of its youth and great depth. Climatic and edaphic factors contribute to the trophic condition in special ways. The Slave river has a great moderating influence and this may be related to the much greater productivity of Great Slave as compared to Great Bear lake. McLeod bay, practically isolated from the remainder of Great Slave lake, exhibits an extreme oligotrophy not previously observed except in small high alpine lakes.

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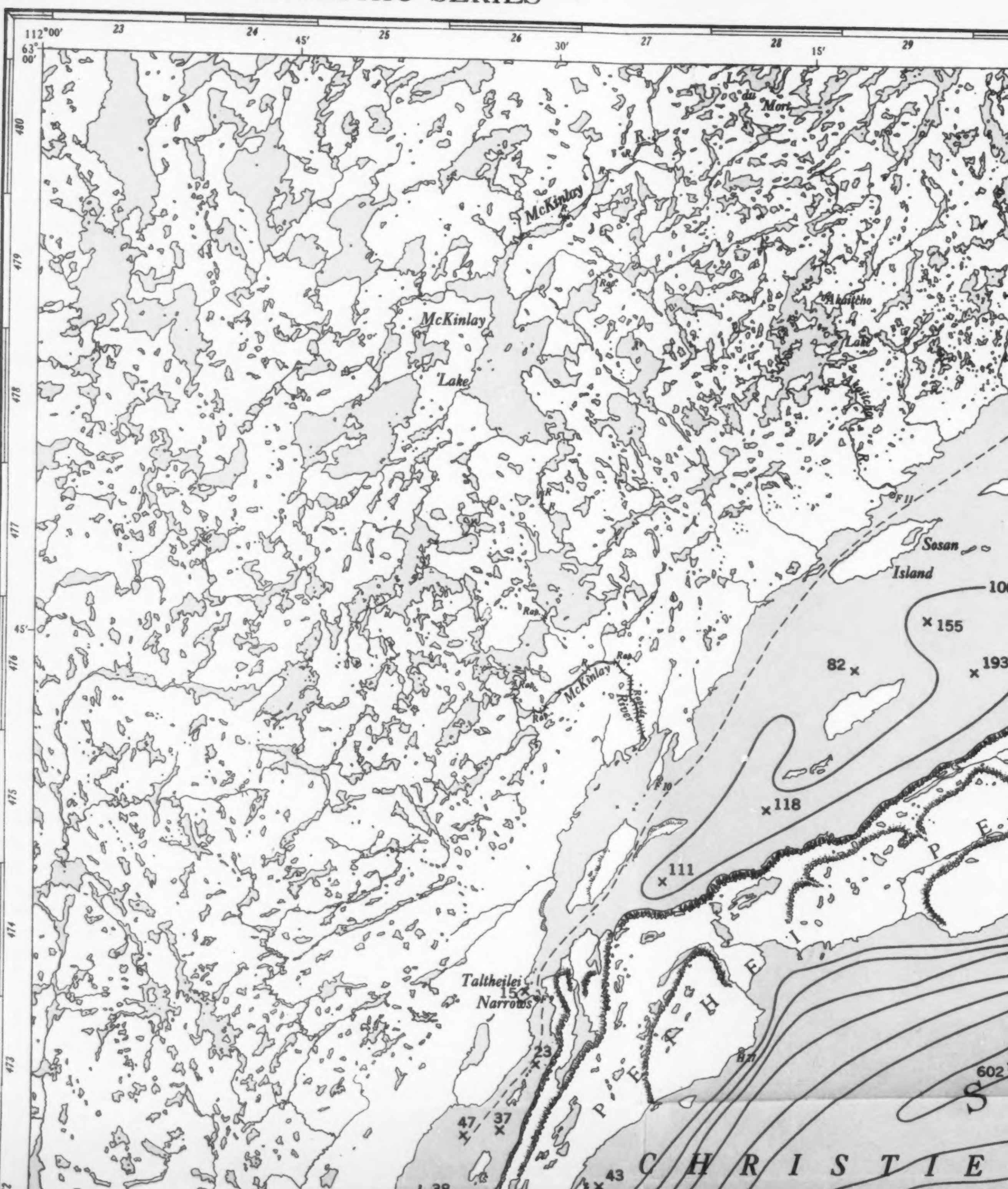


85-I and 85 J)

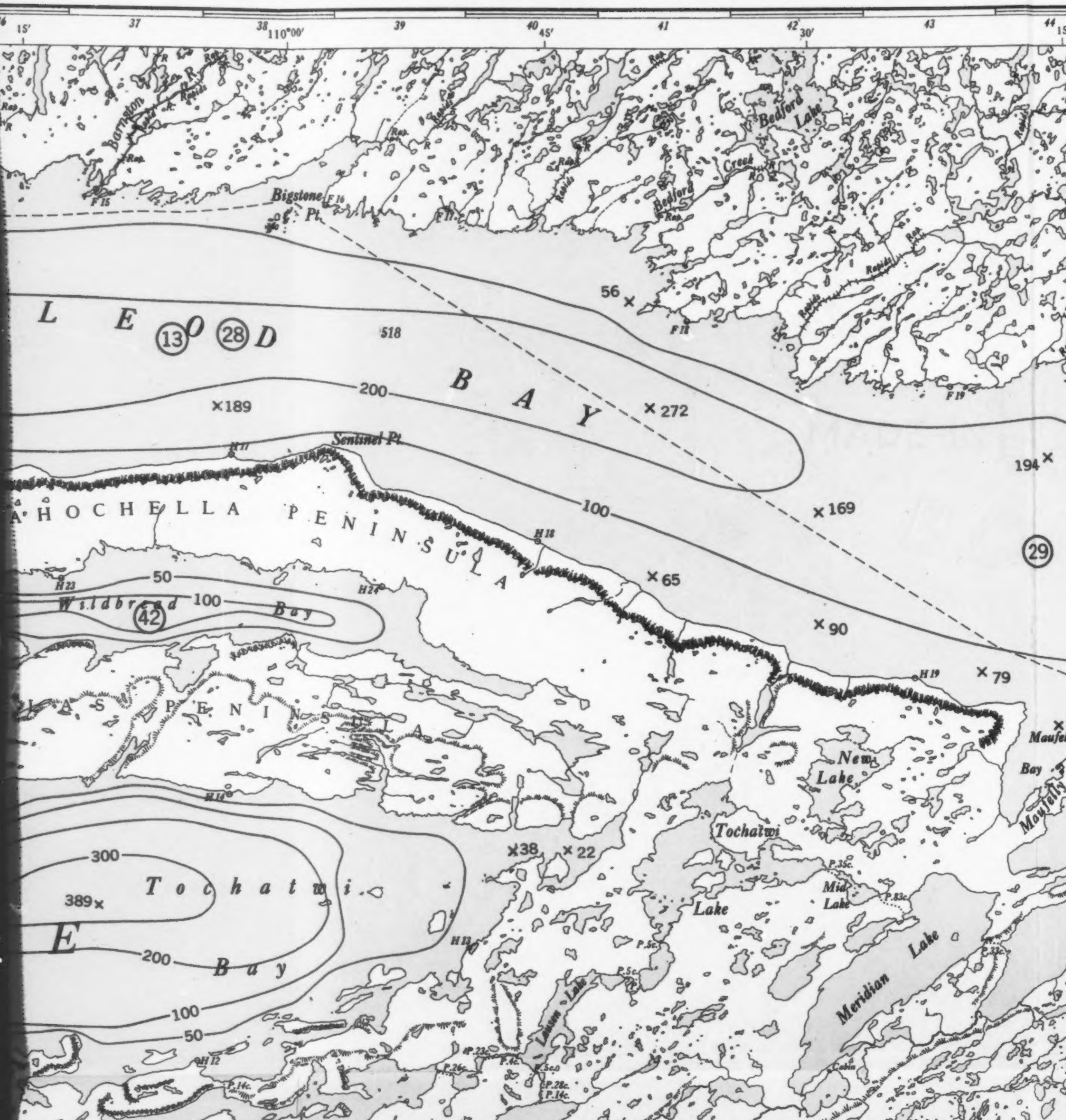
FIGURE 7

EAST ARM O

NORTHW

ST ARM OF GREAT SLAVE LAKE
NORTHWEST TERRITORIES

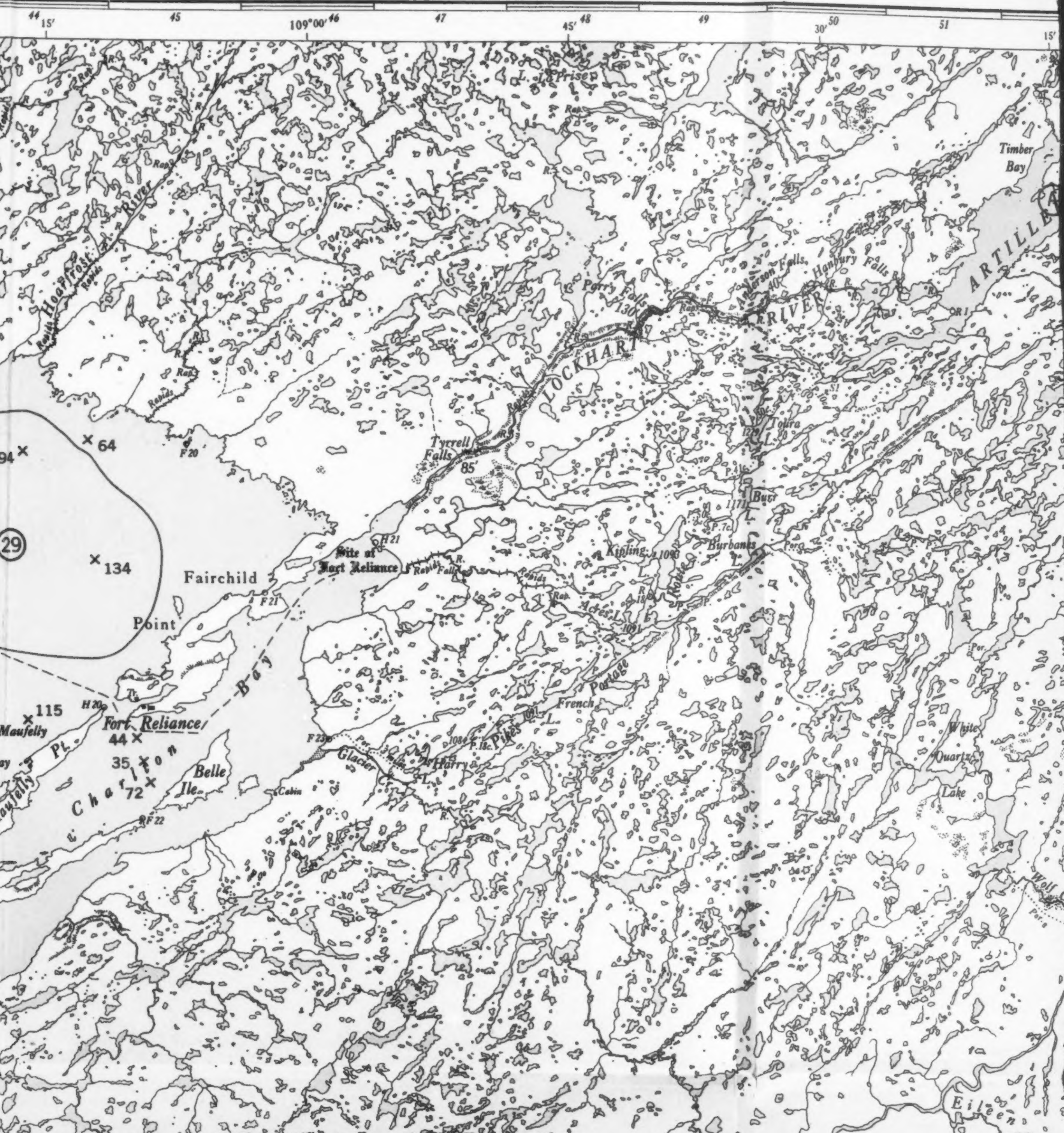
SCALE 4 MILES TO 1 INCH



Depths and depth contours in metres

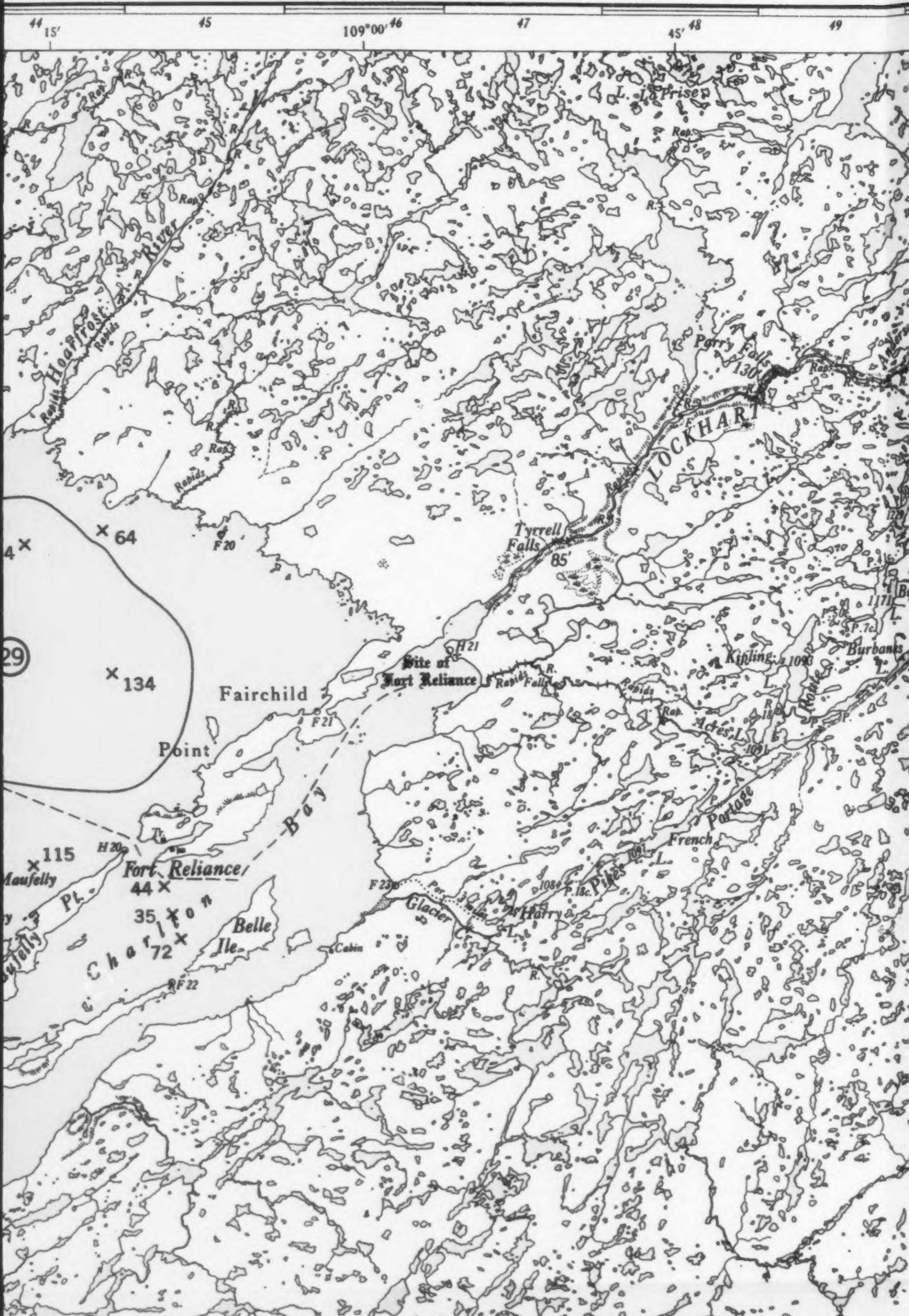
Location of stations .... (36)

SH

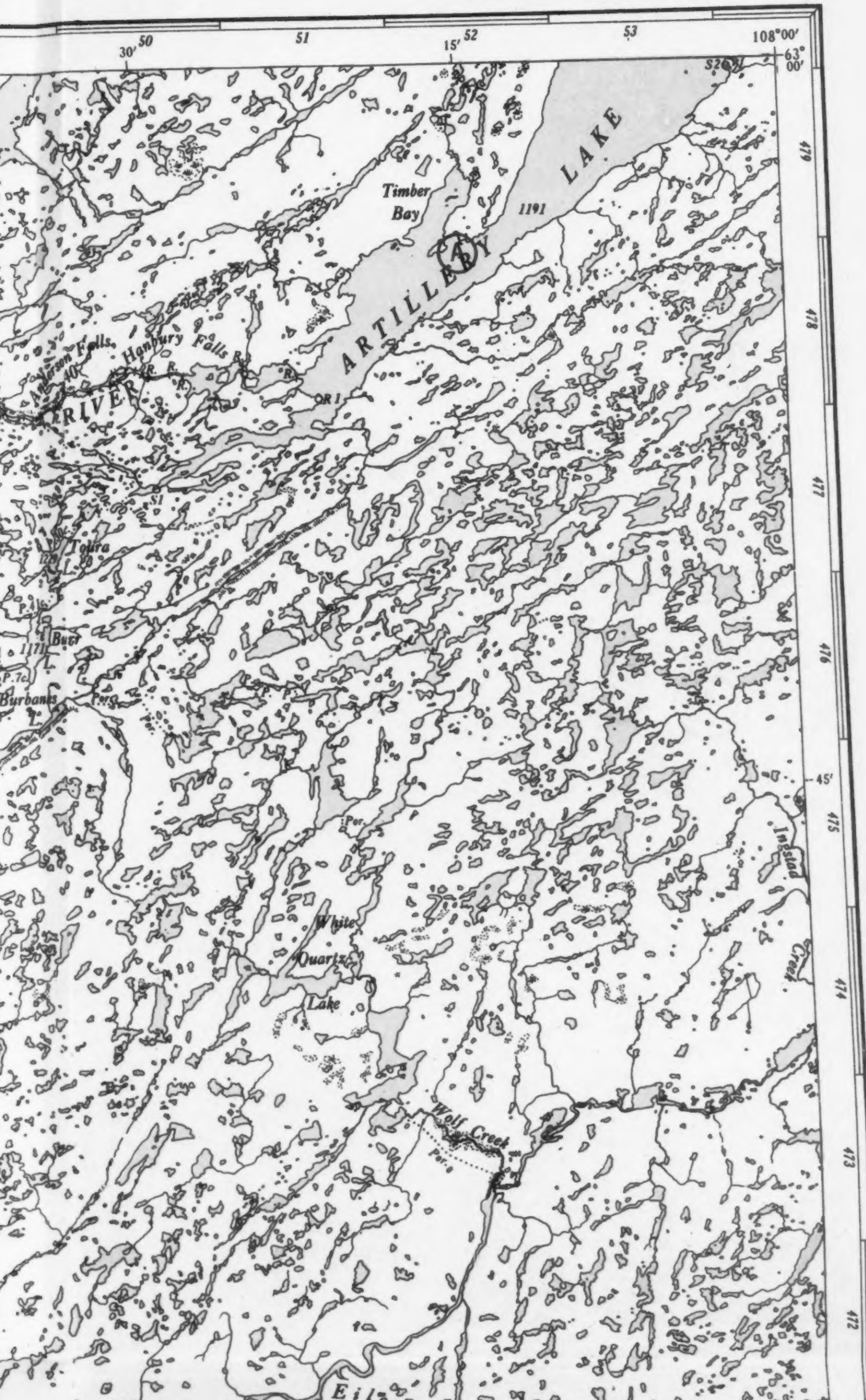


Depths and depth contours in metres

Location of stations 36



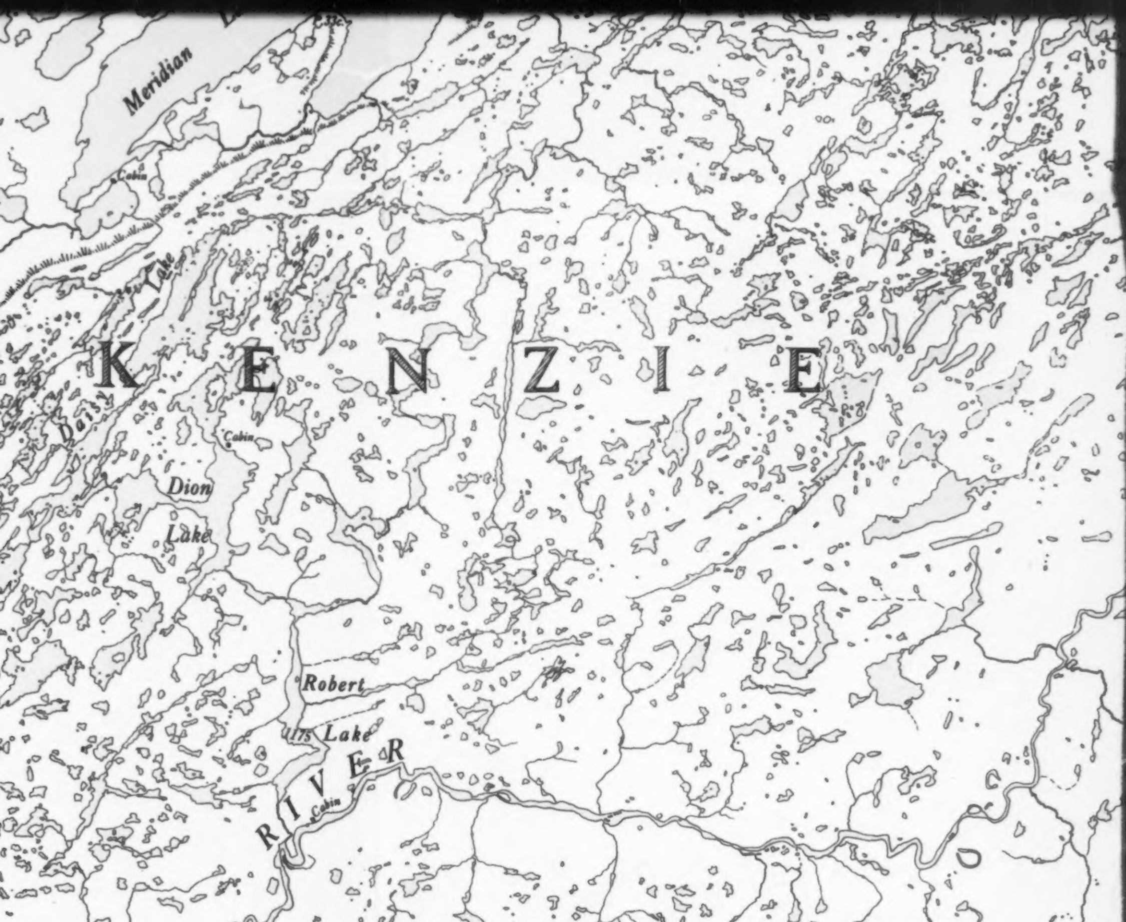
SHEETS 75L AND 75K

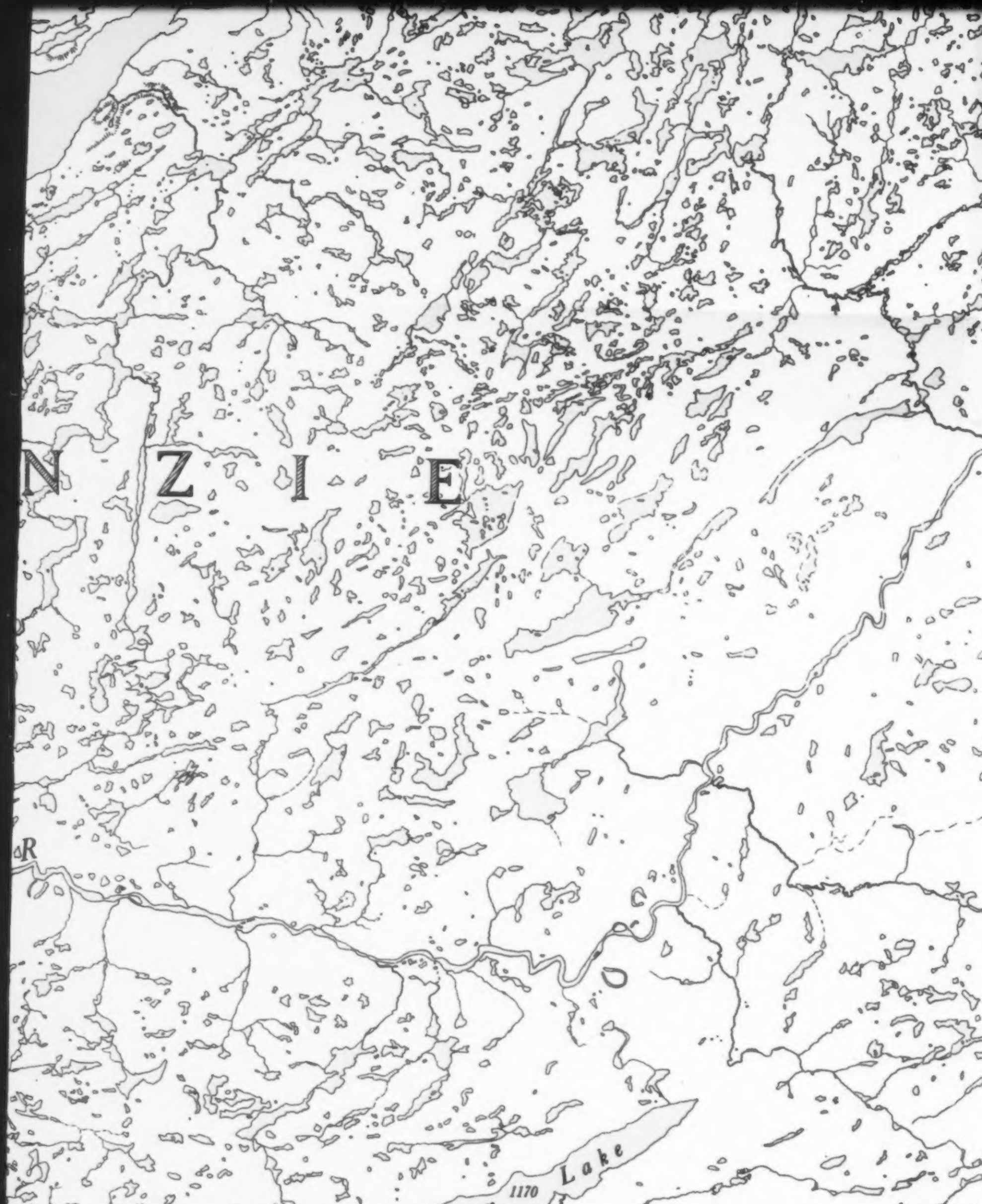


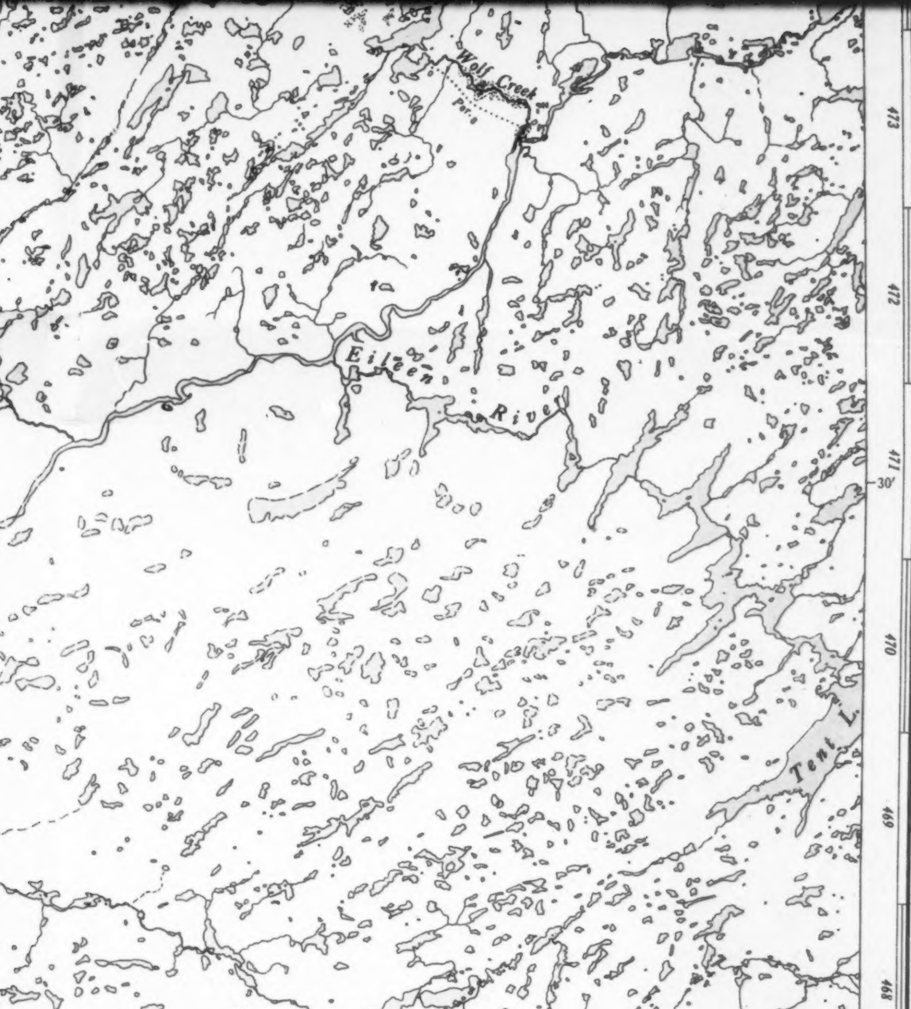

(Yellowknife Bay 85-I and 85 J)
Taltheilei Narrows
CHRISTIE
GREAT
REDCLIFF ISLAND
ET-THEN ISLAND
Sachowia Pt.
Utsingi Pt.
Pekanatui Pt.
Pte. à Tuer
Basile Bay
Basile Lake
Murky Channel
McDONALD LAKE
Rapids
Cabins
P.70c.
50
100
602
218
248
238
202
170
194
143
60
28
108
198
158
80
96
47
37
38
36
43
23
15
56
30
12

SLAVE
LAKE
BAY
DISTRICT
Pearson Point
Inlet
Portage
STARK LAKE
McLean Bay
Murky Lake
Lac Duhamel
Ogilvie Lake
Fairbairn Lake
Channel
Snowdrift
Falls
Rapids
Rap.
400
500
600
614
612
610
602
518
200
100
50
30
24
57
36
35
41
14
P.46c.
P.6c.
P.11c.
P.27c.
P.30c.
P.50c.
P.35c.
1350

Bay
100
50
H12
P.14c.
P.26c.
P.4c.
P.28c.
P.14c.
P.5c.
Lawson Lake
T O F M A C
L A K E
Wilson Lake
P.27c.
Bay
1365
1385
Rap.
Rapids
SNOWDRIFT
1115
Rap.
Rap.
Siltaza Lake
1160


Meridian
Cabin
Daisy
Lake
K E N Z I E
Cabin
Dion
Lake
Robert
175 Lake
R I V E R
Cabin
Noman
1170
Lake
1260
KE


N Z I E
R
Noman
1170
Lake
K E



Wolf Creek
Por.
Eileen River
Tent L.
Jones Lake
Alexander Lake
Satin Lake
Nelson Lake
473
472
471
30′
470
469
468
467
15′
466